AN OUTLINE OF FORESTRY

BY

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Whilst the main object of this work is to provide for students on their initial approach to the subject, an explanatory outline of the kind of knowledge they will have to acquire, it is hoped that it will prove useful to others who are interested in the subject.

Though it is generally known that the British Empire contains vast forests of great actual and potential value, and that in Britain itself the Forestry Commission is engaged in creating forests by planting trees on a large scale, few members of the general public understand the nature of forests and the meaning of scientific forestry.

The book is not intended to supply the theoretical knowledge required for the practice of forestry, which will be obtained by professional students from lectures and other works. Yet, something more than a bare outline is required to stimulate interest which will lead to understanding; the authors have therefore felt compelled to provide rather more information on some aspects of the subject than the professed object of the book would seem to require.

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S. K. Dutta.

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Oak grown in close forest. Age about 400 years. Height to lowest branch 78 feet. Girth at breast height 13ft. 10ins. (*See:* p. 57.)

(Bercé, France.)

Frontispiece.

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PREFACE

It has been said that the foundation of knowledge is the asking of the right questions. Most British foresters have had the experience of being asked such a question as " What do you foresters do?" supplemented, perhaps, for the purpose of provoking a reply, by the additional query: " Do you just cut down trees?" Most of us find questions of this nature, put under circumstances unfavourable for launching forth on the discursive lecture which would be necessary to enlighten the ignorance revealed by the enquirer, embarrassing; we probably return an evasive answer, conveying, at the most, a suggestion that there is some resemblance between forestry and agriculture. The enquirer is apt to pass on with his original ideas of the spontaneity of tree growth and the redundancy of specialists to supervise it, in no degree dispelled. The ignorance of the general public arises from the fact that, until quite recently, the British race (the statement applies to most parts of the British Empire, as well as to Great Britain), has not been compelled, by economic circumstances, to take an interest in the conservation of forests, and the forester is still very far from being an established feature of the rural community with well recognised activities, as he is in many European countries.

Interest in forestry is, however, growing, and whilst the main object of this work is to provide for students on their initial approach to the subject, an explanatory outline of the kind of knowledge they will have to acquire and to place them on the road to the asking of the right questions, both of themselves and their instructors, it is hoped that it will play its part in dispelling the ignorance referred to above and prove useful to those laymen who are interested in the subject and have a serious desire to know what it is all about.

This book has no claim whatever to be considered as a text-book on forestry or any branch thereof. Primarily, it is not intended to supply any of the theoretical knowledge which is required for the practice of forestry and which will be obtained by professional students from lectures and reading other works. On the other hand, something more than a bare outline is required for the purpose of stimulating interest which will lead to understanding; and the authors have therefore felt compelled to provide rather more information regarding some aspects of the

subject than the professed object of the book would seem to require. Trees and the locality provide, as it were, the material on which forestry works, and it is necessary to deal at some length with the nature of these, in order that the necessity for the processes subsequently referred to may be understood.

Technical terms have been avoided as far as possible but cannot be altogether eliminated. Generally those peculiar to forestry are explained on the first occasion of use, but these, as well as those used in related branches of science are all explained in the glossary.

T. T.
M. R. K. J.

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INTRODUCTION

Meanings of the word "Forest." — The word *Forest* has changed its meaning during the course of time as the social life of the people has changed. In feudal times it was applied to an area of land over which the king claimed the exclusive rights of the chase. In order to protect these rights and serve the interests of the game, certain laws were enacted whose validity was confined to the areas declared to be "forest." Such areas were not necessarily completely occupied by trees, but as they were for the most part situated in districts where the soil was comparatively poor and the population scanty, the natural vegetation, whether of woodland or heath, was less disturbed than in richer and more populous parts of the country. Nevertheless, fields and pastures as well as woodland and waste were included in lands administered under Forest Law. Forest Law virtually came to an end in England about 1640, but was only legally abolished in 1817. Nowadays the term *Forest* is rather loosely applied to all woodlands and to open waste where deer stalking is practised. The term *Wood* conveys more clearly to the mind an area completely covered with trees. In Britain we are accustomed to comparatively small woods, generally isolated from each other, though, in large wooded areas, the several parts may receive individual names. In Forestry, a Forest may be taken to mean a large area of wooded land or a collection of woods of large aggregate extent, under one ownership or management. The word *Forest* has also a special technical meaning to the Botanist and Plant Geographer. It denotes a type of vegetation in which trees are the principal members, as distinct from other types in which the dominant plants are of a different kind, such as grassland, heath, tundra, etc.

Destruction of Forests.—It is estimated that about 22 per cent. of the land surface of the earth, excluding the polar regions, is at present occupied by forests. They are found in a great variety of climates and soils, from the tropics to the arctic regions, and form a very important constituent in the natural vegetation of the globe. They have come into existence in certain regions because the climate and soil are suitable for the growth of trees in masses, and, if they are not interfered with, they are stable and permanent plant formations, able to hold their own and resist the invasion of their territory by other forms of vegetation.

In prehistoric times, forests occupied a much larger proportion of the surface of many countries than they do at present. They have disappeared to a greater or less extent owing to the action of man. At first in wooded countries the forest was regarded as superabundant. The small quantity of its products required by the local inhabitants could be supplied without appreciably diminishing the store. As the population increased, the forest was cleared to make room for agriculture and its *regeneration, i.e.,* the replacement of old trees by young growth, prevented by the grazing of domestic animals or by fire. The growing demands for timber and fuel took toll of the remaining forest. In modern times, with improved methods of transport, the exploitation of forests to supply timber to distant markets has brought about the destruction on a scale formerly unknown.

Value of Forests.—Forests are of value to man in a variety of ways. They supply timber and fuel and a number of other products, as well as harbouring game and providing grazing for domestic animals. These services have been recognised from time immemorial, but, with increasing knowledge, it has come to be recognised that the presence of forests may be of great significance in the life of the community in other ways. They may be an important means of protecting the soil from erosion on steep slopes, checking snow slides and avalanches in mountain regions. They often exercise a great influence on the flow of water on streams and rivers. They beautify the countryside and afford opportunities for healthy recreation. Indeed, the absence of local supplies of timber and firewood may, in certain circumstances, be less serious for the welfare of the population than the other evil effects of the disappearance of the forest.

Demand for Conservation of Forests. "Forestry."—Though the history of the destruction of forests differs in different countries, there arises, sooner or later, in every civilised community where such destruction has gone too far, a demand for the conservation of the remaining forests, an improvement in their yield of timber and other produce and even a desire to create new forests in place of those that have been destroyed. In consequence, there has developed, in the course of time, the art of *Forestry,* which in its broadest aspects concerns itself with the treatment of forests so that they may best serve the interests of man.

As forests are so varied in their nature and serve the community in so many different ways, the immediate objects of forestry and the means by which it is sought to attain them are also very varied. The setting out of those aims and the relation-

ship of forestry to other forms of human activity are the subject of that branch of forestry known as *Forest Policy*. It includes the *National Forest Policy;* that is the attitude of the State towards forestry as expressed in the various laws, and financial measures which affect it. It also includes the Forest Policy of the Owner of the Forest, who is in a position within the limits of the law, to decide what shall be the objects of the forester's efforts. These may be economic—*e.g.* the obtaining of a regular and permanent income from the growing and sale of timber or fuel wood—or they may be the maintenance of the forest in the interests of sport or amenity or as a protection for adjoining property.

When the State itself owns and controls a greater or smaller proportion of the forest area of a country, it is able to manage its forests in accordance with the requirements of the social and economic life of the people as a whole. The policy of the State as owner of forests, thus merges into the National Forest Policy. One of the benefits to the State is the income which may be derived from its forest, and generally speaking, if forestry is practised at all intensively, whether under State or any other form of ownership, its objects are mainly economic, though other considerations may be given weight. The State may, however, in the interests of the community, have to take over the control of forests whose position and nature make them highly important for protective purposes though the working of them may be unremunerative.

If the forest is to continue to play its part in serving the interests of man, the first thing that must be ensured is that it shall continue to exist. No treatment which is applied to it, whatever may be the temporary benefits derived, is justified if it leads directly or indirectly to the destruction of the forest or even its deterioration. It must be recognised, therefore, that there are limits set by nature to the freedom with which the forester can interfere with its life. In unfavourable localities, where the conditions for growth are poor and owing to the climate, the nature of the soil or the activities of the local inhabitants, the existence of the forest is precarious, the forester has generally all he can do to keep his forest in being and ensure its regeneration. He is forced to confine his efforts to assisting nature and protecting his forest, so far as he can, from injurious influences. In such cases forestry is not expected to pay directly. The cost of the operations may exceed the value of any material which may be extracted, but if he can preserve and perpetuate the forest and improve its efficiency where it would otherwise tend to deteriorate and disappear, the forester may be doing work of great importance to the community.

In more favourable localities the forest is much more stable and can stand more serious interference with its life. Here the objects of forestry go beyond mere maintenance and protection and include the production of timber and fuel. Forestry becomes more intensive, *i.e.* more labour and money are expended on it because the increased value of the products justifies the cost. The more vigourous the growth of the forest and the greater its accessibility, the more intensive may forestry become. Nevertheless, even the most intensive forestry can never be so intensive as other forms of crop cultivation. The forester has to accept the natural conditions of soil and climate and the type of forest suited to them. He cannot, as the farmer does, improve the conditions for his plants by selecting fertile soil, maintaining it in good condition and even improving it by repeated cultivation and manuring, nor change his crop or strain of seed at short intervals. His means of useful intervention in the growth of the forest are limited, but he can, on the other hand, by injudicious interference, destroy what it is his business to preserve and improve.

Silviculture.— The branch of forestry which deals with the growth and treatment of woods, their regeneration and establishment is known as *Silviculture.* In silviculture the forest is dealt with as a community of living plants. In order that the treatment of woods should be successful, it must be based upon a knowledge of the nature of trees and of the forest. The *Foundation of Silviculture* is the study of trees and communities of trees in relation to their environment, *i.e. Forest Ecology.* From this study, it is sought to determine how the forester can intervene in the growth of his woods to guide their development, improve their production and ensure their regeneration. As a result of this study and the lessons of past experience it has been possible to devise certain methods of treatment adapted to various conditions. These methods, their merits and limitations are dealt with in *The Practice of Silviculture.*

Forest Protection.—In order to ensure the wellbeing of his forest, the forester must be acquainted with the various dangers to which it is exposed and understand how to minimise or combat them. *Forest Protection* deals with a variety of injurious agencies and involves a knowledge of such sciences as Zoology (especially Entomology) and Plant Pathology, of the nature and effects of injurious natural phemomena and fire, and the activities of local inhabitants and their influence.

Forest Bionomics.—Silviculture and Forest Protection have to do with the forest as a community of living things, individually and collectively subject to the laws of nature. These branches of Forestry may be grouped together under the general term

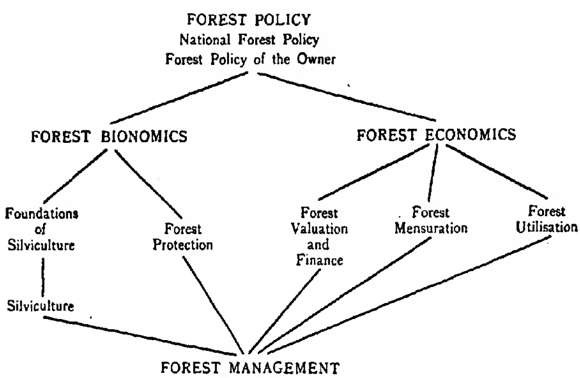
Forest Bionomics. The word *Bionomics* is used in the same sense as *Ecology*—the relationships of living organisms to their environment, and includes the study of plant communities of which the forest is a type. The environment comprises all the conditions of the outer world which affect the life and growth of the plant or plant community, such as climate, soil conditions, and the activities of living beings, plants and animals, among which man must be included. The activities of man, considered as factors in the environment, while they differ from the other factors in that they may be consciously directed and controlled, are fundamentally the same as those of other animals. The responses of the forest to man's actions are just as regular and subject to just as rigid natural laws, as its responses to any other factor. It is therefore quite justifiable to include silviculture under Forest Bionomics, as that part of human activity in the forest which is consciously directed towards influencing growth in certain ways. Other human activities may be deliberately and others unconsciously antagonistic to the forest and to the aims of silviculture, and may be classed with the injurious agencies dealt with under Forest Protection.

Forest Economics.—Besides being a biological association, however, the forest is a productive asset. It is, as it were, a factory for the production of timber, and has, therefore, an economic aspect. The branches of forestry which have to do with the economic side may be grouped together under *Forest Economics*. *Forest Valuation and Finance* deals with the relationships between costs and values in forestry. *Forest Mensuration* is a part of Forest Economics as it is indispensable for determining one of the elements of value, *i.e.* the volume of produce, and for estimating the rate of production and predicting the growth of the future. *Forest Utilisation,* dealing, as it does, with the felling, extraction, transport, conversion and marketing of timber and other products of the forest, is also included under Forest Economics.

Forest Management.—Even when, as in the case of protection forests, amenity woods, etc., the forest is not worked in order to bring in a tangible income, the cost of the operations is expected to be in reasonable relation to the benefits expected. In forests worked for a profit, the importance of economics is more obvious and direct. The relating of the economic side of forestry to the silvicultural or bionomic side, is the province of *Forest Management*. The operations of silviculture are intended to guide the development of the forest in order to produce material or effects of service to man, whilst at the same time ensuring that the forest shall be protected and perpetuated. Within certain limits, these operations can be modified to pro-

duce different results. *Forest Management* prescribes the nature, time and place of such operations, with the object of carrying out the policy of the proprietor—whether his aims are economic or otherwise. Taking account of the nature of the forest, the species and local conditions which determine the limits within which it is free to work, it endeavours to ensure that the operations of silviculture shall be carried out in due order and be of such a nature as to give the desired results, whether in the regularity, size and permanence of the income received or in the other services which the forest provides. The instrument in which Forest Management sets out its aims and prescribes the means by which it proposes to attain them in a given case, is the *Forest Working Plan.*

The above-mentioned branches of Forestry are not independent of one another. Thus—silvicultural measures are limited by considerations of cost and influenced by considerations of Protection; the most economical methods of exploitation may be excluded by silvicultural or protective reasons. The student of Forestry, confining his attention to one branch at a time, is apt to lose sight of the relationships between them. The scheme given below is intended to show only the main lines of connection. For example—some parts of Forest Protection have nothing to do with Forest Bionomics, *e.g.* that against theft of forest products already cut. In the main, however, Forest Protection has to deal with agencies which damage the trees or the forest, as living things. On the other hand, Protection against damage by Man nearly always involves questions of Forest Law and so is connected directly with Forest Policy.



PART I

CHAPTER I

FOREST POLICY

Forest Policy is that branch of Forestry which deals with the social and economic aspects of forestry and considers, especially, the duties of the State as regards forests, so that they may meet the demands of the community in the highest possible degree and the most economical manner.

1. **The Utility of Forests.**—Forests are of value in the life of the community in a number of ways. They serve human requirements, directly by producing materials which are useful to man, such as timber, fuel, bark, fruits, resins, gums, drugs, etc., and indirectly through the influence they exert on the climate, water supply, stability of the soil, the healthiness of the country, etc. Their beauty and the opportunity they offer for healthy exercise and recreation, hunting and shooting, are contributions to the welfare of the community whose value is more and more appreciated as the country becomes industrialised and the area of forest diminishes.

The private owner of a forest property is likely to be concerned with the benefits he can himself obtain from it, and especially in the marketing of its products. On the other hand, the community, besides being interested in the supply of forest products, may be even more concerned with the indirect benefits which the presence of the forest confers. Owing to the time it takes to grow timber, the owner of the forest, in general, receives little or no direct benefit from the crops which he himself has planted. He reaps what his predecessors have sown, and there is a danger that an unscrupulous or impoverished owner may cut more and plant less than he should do if he is to hand on the forest to his successors in as productive a condition as he received it. By so doing, he may destroy the forest in whole or in part and not only rob his successors but inflict injury, both immediate and prospective, on the community.

The immediate injury to the community will generally be in depriving them of the indirect benefits which the presence of the forest confers. The withdrawal of protection from erosion, land

slides and avalanches in mountain country may injure the lands below and the removal of the forest cover may produce unfavourable effects on the water supply to springs and rivers. The ultimate injury done may also include a reduction in the supply of wood and other produce for local and national industries.

The State, as the guardian of the interests of the community, may be forced to interfere with the freedom of the owner to do what he likes with his forest, by making laws and regulations restricting exploitation. On the other hand, the State may find it advisable to do something to encourage owners to manage their forests properly by financial assistance, remission of taxes, imposition of protective duties on foreign forest products and the provision of technical education and advice, etc.

The importance of forests to the country and the place they hold in the national economy varies with circumstances. It is the duty of the State to secure that the requirements of the future will be adequately met by laying down a definite forest policy.

2. **National Forest Policy.** — The Forest Policy of the State should be based upon the requirements of the country for the direct and indirect services which forests can render and their importance in relation to other methods of utilising land.

It may be that it is more economical to import supplies of forest products from abroad than to grow them at home; but there is danger in complete dependence on supplies which may be cut off in case of war or upon the permanence of which reliance cannot be placed. Therefore, whilst the more urgent demands of agriculture will confine the maintenance of forests supplying products for export, to thinly populated countries of mountain ranges and poor soils, most countries find it desirable to maintain a certain minimum area under forest for home requirements. Richness in coal, lignite, peat, iron ore and other substitutes for wood will reduce this minimum requirement.

As regards the *indirect* effects of forests, the most important considerations are the configuration of the land and the climate of the country. A sea-bound country, owing to its equable and moist climate is generally less in need of forests than an inland country; a mountainous country more in need of them than a low lying one, owing to the beneficial effects of forests as regards erosion, the carrying away of soil, sudden floods and the sustained feeding of springs.

Changes in the methods of agriculture, fall in price of certain agricultural products, alterations in public taste in foodstuffs, etc., may throw out of cultivation lands formerly productive or reduce their productivity and the population required to work them. In such cases the question of *afforestation* merits consideration, both from an economic and social point of view.

3. The State as Forest Owner.—Whether the State should own and manage forests or whether it is advisable to leave forestry to private individuals is a question which comes up under Forest Policy. Most States own a certain proportion of the forests in their respective countries, but the proportion varies enormously. In the older European countries, the state forests are mainly the remnants of those forming part of the property of the ruling house. In newer countries, the land is generally taken to belong to the State except where granted to individuals or corporations under laws in force at the time of grant. The advisability of State ownership of forests may be debated on general grounds—as to how far the State should engage in trading in competition with private individuals. On the other hand, it may be argued that the peculiar nature of forestry makes it more suitable than other forms of activity for the State to undertake.

In order to provide regular supplies of timber, forests have to be built up of a series of age classes, the oldest of which is cut each year, and this requires for economical working and the profitable utilisation of the services of the highly skilled and trained forest officer, a considerable area of land, which it is outside the power of any but the most wealthy individual to provide. It requires the sinking of a large capital and a continuous and disinterested management, which is best provided by the State. Owing to considerations of national defence, the special requirements of industry, etc., it may be in the general interest to grow timber of sizes and kinds which are not the most remunerative to the owner, but which the State, with its wider outlook, may quite suitably be called upon to provide. In certain cases the forests are subject to rights and privileges exercised by the local inhabitants which form an essential element in their lives. The forest, in such cases, may be of little or no direct value to the nominal owner, but its protection from damage through ignorance or carelessness, or the abuse of the rights is essential for the existence of the community and is clearly the function of the State to secure.

The extent to which the State engages in Forestry directly and the amount of control it exercises over the forests of corporations and private owners, varies in different countries. In some States, forests considered to be of special importance owing to their protective character, are subject to State regulation or managed by State forest officers. Forests belonging to local authorities, corporations and charitable trusts, etc., may be managed by the State in the interests of continuity and conservation. In other countries, the State exercises little or no control over private or corporation forests.

4. The Objects of a Forest Policy. — The principal objects of a Forest Policy should be:

(1) To ensure that there shall be an adequate area of forest in the country, having regard to present and future conditions.
(2) To protect the present and future forests from injury by man, fire, pests and diseases as far as possible.
(3) To maintain and, if possible, improve the productivity of existing forests.

If the existing area of forest in a country is judged to be inadequate, the question of afforestation by the State and the means by which private owners may be induced to plant, come under consideration. Where the forest area, though at present adequate, tends to be continuously reduced by exploitation or by clearing for settlement and agriculture, the demarcation of permanent forests and their maintenance as such may be the main features of the State Forest Policy. Though, in general, it will be agreed that the land suited for agriculture should be devoted to that use, it has often been the case that large areas of forest have been laboriously cleared by settlers who have been encouraged by easy terms of land acquisition, only to find that, owing to distance from markets, unforeseen difficulties with the climate, exhaustion of capital, etc., they are unable to make a living. In such countries, forest policy should be part of the general *Land Utilisation Policy* of the State and lands judged to be permanently or for a long time unsuitable for settlement reserved as *Forest Lands*.

The forest policy should be given the force by law by incorporating it in an Act or Statute of the Legislature and a State Forest Authority established, charged with the duty of carrying out the policy, and given the powers necessary for the purpose. The details will depend on the conditions of the country but, in all cases, it is of the greatest importance that the policy and the provisions for carrying it out should not be subject to capricious variations at short intervals through political or economic causes. The Forest Authority should have at its disposal a revenue which it can count upon for a period of years, so that its plans may be made in advance and its work proceed in an orderly manner.

5. The Forest Policy of Great Britain. — Up to the time of the Great War, Britain relied very little on her own woods for supplies of timber. The area of forest in the United Kingdom before the war was estimated at 5,180 sq. miles, and amounted to 4·3 per cent. of the total area of the country. Of the forest area, 96·3 per cent. belonged to private individuals, whilst the State controlled only 2·6 per cent. and corporations such as the Ecclesiastical Commissioners, Colleges, etc., owned the remaining 1·1 per cent. Britain was the largest importer of

timber of all the countries of the world. The average quantity of timber imported during the ten years before the war was over 10 million loads per annum, of which 95 per cent. was coniferous. The Forestry Sub-Committee (referred to below) estimated that to produce this quantity of timber at home, no less than 14,640 sq. miles of additional land would require to be afforested.

Though a certain amount was done by the Government to encourage forestry in Britain by the provision of technical education and advice, up to the end of the war the country cannot be said to have had any forest policy.

The war brought home to the Government and the country generally the serious consequences of this practically complete dependence on foreign supplies. The importation by sea of such a bulky material as timber in the quantities consumed, demanded ships which could ill be spared from the transport of food, munitions and men and the Government was forced to make an organised effort to obtain as much as possible of this essential commodity from Britain's own woods. As a result, the already small area of British woodlands was seriously depleted. Not only was practically the whole stock of mature coniferous timber cut, but a large proportion of the younger coniferous plantations were felled and used for pitwood. The best ash and a considerable amount of the best oak were also used up.

In July, 1916, the Forestry Sub-Committee of the Reconstruction Committee was set up " to consider and report upon the best means of conserving and developing the woodlands and forestry resources of the United Kingdom, having regard to the experience gained during the war." The report of this Sub-Committee served as the basis of the Forestry Act of 1919.

The Sub-Committee reported that in their opinion the production of home-grown timber was altogether insufficient, that the prospect of future supplies was uncertain and that, in case of emergency, security could only be obtained by having a sufficient stock at home. They calculated that the additional area of woodland required to make the country independent of overseas supplies for three years of emergency was 1,770,000 acres of conifers and 100,000 acres of hardwoods, and recommended that the State should undertake the task of providing them. They were of opinion that there was ample waste land suitable for the purpose of growing the required area of conifers, the afforestation of which would give considerably more permanent employment than the present method of utilisation—chiefly sheep grazing—and produce a larger return.

In the case of the conifers a rotation of 80 years was assumed and theoretically one-eightieth of the area should be planted each year, but owing to the serious depletion of the existing stock of

timber, it was proposed to plant two-thirds of the area in the first forty years and one-third in the second half of the rotation. In the case of hardwoods, it was considered sufficient to plant 1,000 acres annually. In addition to providing for the planting of the above areas, the Sub-Committee recommended that steps should be taken to encourage private owners to replant woodlands devastated during the war, and to improve, by research, technical education and advice, the standard of forestry in the country. Finally, they recommended the appointment of Forestry Commissioners provided with the necessary powers and funds, to carry out the policy of the Government.

On the basis of the Sub-Committee's report, the Forestry Act of 1919 was passed, providing for the appointment of eight Forestry Commissioners, charged with the duty of promoting the interests of forestry, the development of afforestation and the production and supply of timber in the United Kingdom.

Since their appointment, the Forestry Commissioners have been working, so far as their finances would permit, on the lines of the Sub-Committee's planting programme, but their plans have, on two occasions, been upset by a reduction in their Parliamentary grant, due to financial crises. Subsequently the financial provision for their work has been increased, and satisfactory progress in afforestation is anticipated in the future. On the other hand, the assumption made by the Committee that private owners, with such encouragement as could be given them, would restore their devastated woodlands and maintain the pre-war areas of forest in production, have not been fulfilled. It looks as if the State will have to undertake an even greater share of the task of building up a stock of growing timber in the country, than was anticipated when the planting programme was drawn up.

6. The Forest Policy of the Owner of the Forest.—It is the privilege of the owner of the forest to decide how the forest shall be used, provided he does not do anything contrary to the law of the land or violate any conditions limiting his ownership in the interests of third parties. The owner of a forest may be a private individual, a corporation (such as an educational or religious institution, public company, the trustees of a charity, etc.), a local authority (commune, town, etc.), or the State. Whether the individual owner exploits the forest for his own benefit, regardless of the future owners' interests, often depends on his character, his consideration for his family and his financial position, but it may also be determined by legal conditions by which he is in effect a tenant for life and entitled only to the income from the estate, whose capital he cannot dissipate. Forests are, however, forms of estate in which it is difficult to

distinguish capital from income, and an ignorant or unscrupulous owner has opportunities of damaging the property undetected.

A corporation, as owner of forests, is, as a rule, more directly concerned with the perpetuation of the income. It has no particular obligations, as the owner of forest property, to foster the interests of local inhabitants or the industries of the country generally, at the expense of the corporation itself. The Managers of a hospital or college, owning a forest, may quite legitimately refuse to sacrifice income which would be devoted to their own particular form of public service, to provide privileges or amenities to the dwellers in or near their forest.

A local authority, owning a forest near or within its administrative district, will naturally be influenced in its treatment of the forest by considerations other than those of pure finance. Recreation, fuel for the poor, public health, local industries, etc., will be taken into consideration in framing its forest policy.

Finally, the State, as the owner of forests, has wider interests than the revenue it can derive from them and the well-being of the local community. National defence, wood using industries of the country generally, conservation of water supplies and flood protection, which may affect regions remote from the forest itself, all come within the purview of the State, which will use its forests as one of the instruments for carrying out the National Forest Policy.

The chief ways in which the owner may benefit from the possession of forest property are:—

(a) the receipt of an income from the sale of the produce,
(b) the enjoyment of hunting, shooting, fishing and other sporting amenities,
(c) the protection of other property from wind, erosion, snow, etc.,
(d) the beautifying of the landscape.

The policy of the owner of the forest may be to obtain one or more of these benefits, and as the treatment for one purpose may carry with it disadvantages for others, he should decide what is the main object of working and to what extent it may be sacrificed so as to obtain other advantages.

(*a*) *The receipt of an income from the sale of forest products.*—The advantages of a regular, approximately equalised annual income from the forest and the conditions which must be fulfilled in order to obtain it, will be explained under *Forest Management*. In most cases, where systematic forestry is practised on a large scale, the object of working is to secure such an equalised annual income, but in smaller estates, the proprietor may have to be content with a more or less equalised periodic income. In addition to being regular the income should, in

general, be as large as the forest is capable of producing and should also be permanent. The rotation, system of silviculture, etc., will normally be settled with reference to these considerations, but there may be others which will require modifications of them. For example, the owner may desire to produce material of certain sizes or species to supply some industry in which he is interested. A pulp manufacturing company may own forests from which it draws supplies of suitable material for its works, or a colliery owner may desire to grow pitwood. The State, as the owner of forest property, may feel it incumbent upon it to grow trees to a greater age than is economically justified so as to provide a reserve of growing timber in the country for use in emergency, or in order that industry should be able to obtain large sized logs which it would not pay private forest owners to produce.

(*b*) *Hunting* and *Shooting* may involve the upkeep of roads and rides, underwood, etc., and the game animals may cause more or less serious injury to young growth, necessitate expensive fencing of regeneration areas, exclude certain silvicultural systems, etc., thus reducing the net return from the forest. It is for the owner to decide to what extent financial considerations must be set aside for the sake of sporting facilities.

(*c*) Considerations of *protection to adjoining lands* may modify the silvicultural system, the choice of species, the rotation and the ordering of the fellings.

(*d*) *Æsthetic considerations* may prohibit clear fellings, the raising of pure woods or even-aged woods, the felling of matured timber, change of species, etc.

It is the duty of the forest manager to carry out the policy of the proprietor with regard to the particular forest under his charge.

PART II

FOREST BIONOMICS

CHAPTER II

THE FOUNDATIONS OF SILVICULTURE

Silviculture is the cultivation of forests for the purpose of satisfying man's requirements for their products in a systematic manner, whilst, at the same time ensuring that the forest shall be perpetuated, and, if possible, made more productive. In former times, silviculture was to a large extent empirical and its methods mainly the result of trial and error. In modern times, it is recognised that a sound silvicultural technique must be based on a knowledge of the nature of the forest and its reactions to interference with its life. The Foundations of Silviculture are therefore to be sought by a study of the structure and life processes of trees, their relations to the environment in which they grow, the conditions which exist among them when growing in communities and their responses to such changes in those conditions as may be brought about by human interference.

1. THE STRUCTURE AND LIFE OF TREES

The study of the structure and life processes of trees forms part of the science of Botany. The training of a forester should include a course of general Botany and a particular study of the special branches of the subject dealing with trees. In his case it is particularly important that he should be encouraged to make his own observations in the field. One of the fascinating features of the life of the forester is his daily contact with nature, and when he has, at the outset of his career, some knowledge of what others have discovered or conjectured about trees, and has, under suitable guidance, made his own observations in the laboratory and in the forest, he will not only be equipped to carry out his duties more efficiently, but will also have placed in his possession a new-failing source of interest.

The most comprehensive summary of what is known about trees from a botanical point of view is to be found in " The

Structure and Life of Forest Trees" by Busgen and Münch, translated by Thomson (Chapman and Hall, Ltd., London) which gives numerous references to original works. This book deals with European forest trees, but refers also to some of the work done on trees in other parts of the world. It is not concerned with the description and identification of the different species. For these the student will have to turn to other books. The "Handbook of Coniferæ" by Dallimore and Jackson contains descriptions of all the known conifers of the world. With regard to broad-leaved trees, which are much more numerous, no similar work exists in the English language. Floras of the various countries describe the tree species, and comprehensive works such as Engler and Prantl's "Pflanzenfamilien" and Schneider's "Handbuch der Laubholzkunde," both in German, include most of the species known when they were compiled. So far as British trees are concerned, there are a number of books of a popular type, which contain descriptions and illustrations. Among them may be mentioned: Step's "Wayside and Woodland Trees," Heath's "Our British Trees" and "Welsh Timber Trees" by H. A. Hyde, which is published by the National Museum of Wales.

It is not possible in this book to devote space to the description of the structure of trees or the distinguishing characteristics of different species, essential as a knowledge of them is to the forester. It will be assumed that the reader has a certain amount of knowledge of the general botany of woody plants and attention will be directed mainly to the life processes of trees and their relationships to the conditions in which they grow. Nothing that the forester can do will alter the essential structure of a tree —he cannot change an oak into an ash or a pine into a spruce— but he can, with sufficient knowledge of the conditions which make one tree differ in size, shape, vigour and healthiness from another of the same species, hope to guide its development by choosing and modifying them. It is proposed therefore to discuss briefly the complicated subject of the relations of trees to their environment. Afterwards something will be said about the form of trees and the way in which it may be modified by the surroundings in which the tree finds itself.

2. THE LIFE PROCESSES OF TREES

In order that they may live and grow, trees, like all other plants, require certain chemical elements and a supply of energy in suitable quantities and suitable forms. It has been found by experiment that the following elements are present in all plants and are essential to their existence: carbon, oxygen, hydrogen, nitrogen, phosphorus, sulphur, iron, calcium, potassium and

magnesium. The carbon is obtained by the leaves of green plants from the carbon dioxide gas present in the air, by the process known as *Carbon-dioxide Assimilation* or shortly *Assimilation*. Some of the oxygen is obtained from the air or from that dissolved in the soil water. The remaining elements are obtained from the soil through the roots, in the form of a dilute solution on water of the salts containing them. The water, carrying the salts, rises from the roots through the stem and branches to the leaves, where most of the water is evaporated into the atmosphere, leaving the salts behind. The elements contained in the salts can be combined with the carbon extracted from the air by the process of assimilation and part of the water to form the various organic substances found in the plant, the materials from which it is built up. The emission of water vapour from the leaves is known as *Transpiration*.

The living cells of the absorbing roots have the power of passing on the watery solution they absorb to the rest of the plant and of forcing it up the stem and branches. In trees, however, this *Root Pressure* is quite insufficient of itself to force the sap up to the height required, and the transpiration stream appears to be kept in motion by the force of evaporation which draws water from the leaves, and is transmitted by means of the cohesion of water, through the conducting channels. The force of evaporation depends mainly on the moisture condition of the atmosphere, but also on the temperature and the state of rest or motion of the air. The parts played by root pressure and evaporation in the maintenance of the transpiration current have not yet been fully determined, though it appears that the latter is very important in the case of trees. It is quite possible that other forces developed in the plant also co-operate.

The emission of water vapour from the leaves and the taking in of carbon dioxide gas takes place through numerous minute openings in the leaf surface called *Stomata*, which, in many cases, are capable of closing or opening to a greater or less extent so that the emission of water can be controlled in time of scarcity.

Assimilation is carried out in the leaves through the agency of the green colouring matter, the *Chlorophyl*. In the presence of *light* the carbon dioxide is broken down, the oxygen it contains liberated, and the carbon utilised to form, with oxygen and hydrogen, the elements of water, the first organic substance easily recognisable as the product of the process: *Starch*.

The process of assimilation absorbs energy, the source of which is light, and this energy is stored, as it were, in the substances formed. The plant is able, by the oxidation of such substances, to obtain the energy again and use it for its vital processes. The carbon contained in the substances consumed

appears again as carbon dioxide. The oxidation of organic substances and the production of carbon dioxide is called *Respiration,* and this process, unlike assimilation, which is confined to the green cells, can go on in many parts of the plant. It requires oxygen and involves the breaking down of plant substances or reserve materials, and is thus the reverse of assimilation. By the processes of assimilation, absorption by the roots and transpiration, the tree obtains the materials it requires for its growth, whilst the energy all comes ultimately from the light and heat radiated to the earth by the sun.

The processes briefly described above, go on in all the higher plants which possess chlorophyl and are influenced by the various external conditions in which the plant finds itself. Heat, light, water supply in air and soil, the chemical and physical condition of the soil, etc., all act upon the plant and affect these vital activities.

3. THE RELATIONS OF TREES TO THEIR ENVIRONMENT

The Natural Habitat. — Every species of tree has inborn characteristics, differing more or less from those of other species, which enable it to live and grow within a certain range of conditions, to which it is capable of adapting itself. This has led to the occurrence of a species in nature, in certain areas or groups of areas which are called its *Natural Habitat.* The natural habitat of the beech, for example, extends over a large part of western Europe, including southern Britain. This does not mean, however, that every site within this area is suitable for the growth of the beech. Soil conditions as well as climatic ones are important and vary greatly from place to place, and the variations in climate, due to elevation, exposure, proximity to the sea, etc., are so wide as to embrace conditions which prevent the species from succeeding on all sites.

The vigour and productive power of a species within the limits of its habitat show a gradation from the *optimum* in which they are at their greatest, to the *minimum* in which the species is only just able to maintain itself. The limits of the habitat of a tree species are often set by its failure, in the conditions which are comparatively unfavourable, to regenerate itself and hold its own in competition with other species, for which the conditions are more suitable. By limiting the competition and assisting in the regeneration, the forester is able, within limits, to extend the habitat of species he wishes to encourage.

The confinement of a species to a certain habitat, limited by surrounding conditions which prevent its migrating further afield, does not necessarily imply that there are no other regions in

which the species in question would succeed. A species from a distant habitat may be quite successful if it is introduced into an ecologically similar region into which it had no opportunity of migrating naturally. It is, however, useless to attempt to grow a tree in localities whose conditions differ markedly from those of its native home. The introduction of *Exotic Species* into the forest may be justified in certain circumstances, but only if careful consideration is given to the conditions in which the tree grows naturally. Even in dealing with species native to the district, the suitability of different sites and the effects of various conditions on their growth are of the highest importance.

Locality. — The word *Locality* is used in Ecology and Forestry to denote the whole complex of conditions which influence the growth of plants in a given place. A locality may be good or bad, favourable or unfavourable, for the growth of a certain species or community of species. In forestry the *Quality of the Locality* is measured in terms of its productive capacity—by the quantity of timber of a given species it is capable of producing. The term has no meaning except as applied to a certain specified kind of tree, as a certain locality may be capable of growing one species well, but more or less unable to support another which requires different conditions. It should be noted, however, that localities which can be classed together as of equal productive capacity for a certain species, may be quite different ecologically. Equal volume production may be the result of quite dissimilar conditions and may be accompanied by considerable differences in the form of the trees, their health and reproductive power and different silvicultural treatment may be called for.

All localities possess certain essential *Factors* without which plant life would be impossible. Light, heat, water, carbon dioxide, soil nutrients, must be present in adequate amount and in forms available for the use of the plants. Localities differ from one another in the absolute and relative amount, distribution, form, and variation of various factors. All must be present and their aggregate effect determines the existence and growth of the plant world. If one of the factors, though adequate to permit of life, is present in an unfavourable form or scanty amount as compared with the other factors, its effect on the plant is relatively very great. A slight change in this factor will have a greater influence on growth than changes in the other factors.

Liebig, the chemist, from his study of the mineral substances required by plants, was led to formulate the so-called *Law of Minimum:* "It is that factor of plant nutrition present in minimum which determines production." The law has since been extended so as to include other factors, such as light, carbon

dioxide, heat, etc. As it is found that excess of a factor may also act injuriously on growth, the law has been given the more general form: " The fruitfulness of a locality is limited by its most unfavourable characteristic." (Vater.) Of recent years, investigators have found other relationships between the growth factors which show that production is not determined by the factor in minimum alone, but depends also on the other factors. Though Liebig's Law of Minimum has had to be qualified in this way, the idea of the *Limiting Factor, i.e.* the one which in a given case has the most powerful influence in limiting growth, is of the greatest practical importance. If it is sought to improve growth, the most hopeful way is to identify and improve the limiting factor.

It is impossible to reduce to figures the effects of the different growth factors and we must be content to recognise only the direction and nature of their action. In the sections which follow, a brief account is given of the relations of the chief factors of climate and soil to tree growth. Subsequently it will be shown how the growth of trees in masses in the forest modifies the factors of the locality and affects the growth of the trees themselves.

4. THE FACTORS OF THE ENVIRONMENT

(*a*) HEAT

Influence of Temperature on Plant Growth. — All the vital processes of plants are affected by the temperature. When the temperature is too low, assimilation, respiration and growth are arrested. Species differ in the amount of heat they require, but, in general, it is found that for a given species, each vital activity begins at a certain temperature, increases as the temperature rises up to a certain amount, and then, when the temperature rises still further, diminishes and finally ceases. There are, therefore, for each vital activity, three cardinal points: a *minimum* at which it begins, an *optimum* at which it proceeds most rapidly and a *maximum* at which it is arrested. The position of these cardinal points and the activity of the function vary with changes in the other factors, and, as, in nature changes in heat conditions are always associated with changes in light, moisture, etc., there would be little advantage in determining them, even if it were not impossible to do so in the case of trees growing in the open. That there is a heat climatic effect on the growth of the different species is evident from their distribution and especially from their marked formation of zones in mountain regions. The difficulty is to express these differences in the heat

climate in figures. It is certain that not only air temperatures in the shade and the magnitude and distribution of their variations throughout the year, but also the radiant heat of the sun and the temperature of the soil influence the growth of trees. Hitherto all efforts to express the heat requirements of different species in figures have had very little success.

Extremes of Heat.— Extreme heat of itself does not often do much damage in the forest. It is true that in hot weather plants and even trees may wilt and wither, but this is due to shortage of water, rather than to too great heat. The temperature of the air never rises so high as to inflict injury on plants, but the direct rays of the sun may warm up solid bodies to a temperature considerably higher than that of the atmosphere, and in some cases this is sufficient to cause injury to living tissues exposed to them. Thus, thin-barked trees, such as beech and ash, sometimes suffer from *Bark Scorch,* by which parts of the rind are killed, when stems, formerly protected by shading, are suddenly exposed. Young seedlings and small plants are sometimes injured through the overheating of the surface soil, their stems being killed at soil level. (*See:* Protection against Heat, p. 133.)

Extreme cold in winter is rarely fatal to native trees and plants. When in a resting condition, the trees of climates with cold winters are protected against injury due to freezing by changes which occur in the cell sap in the autumn. Species vary in the efficiency of such protection, and naturally those which are poorly adapted suffer most. Trees from regions where no excessive cold is experienced at any time of the year are unable to stand low temperatures, whilst many arctic species—certain willows, spruces and firs—will withstand temperatures as low as −76 deg. F. for a part of the year. Even these species, however, only stand very low temperatures during the period of vegetative rest and all may suffer from frosts occurring during the growing season. So far as is known, there is no region in the world in which the growth of trees of every kind is prevented, merely by the lowness of the winter temperature. In Europe, the yew, silver fir and green Douglas fir are apt to freeze in the open in very cold winters, and, among broad-leaved trees, the walnut and many fruit trees.

The injury done to trees in frosty weather is not always the result merely of low temperatures. Evaporation in cold dry winds and clear days, which deprives tissues of water which cannot be replaced owing to the freezing of the soil and the conducting channels in the stem and branches, contributes.

The protective changes in the plant which make it resistant to damage by winter frosts begin to be reversed when it pre-

pares to start growth again. The organs and tissues become more and more sensitive, and shoots, leaves and flowers, in process of development, are often easily damaged by frosts, not nearly so intense as those endured by the plant without injury during the depth of winter. Late spring frosts are therefore specially injurious. These frosts are generally due to the radiation of heat from the soil at night, so that the danger is greatest close to the ground, whilst at from three to ten feet above ground the so-called *Frost Level* is passed and little or no injury is done. Anything which reduces radiation of heat, such as cloudiness of the sky or the shelter of a light overwood, reduces the danger of frost.

The frequency and severity of frosts vary greatly from place to place, even within short distances. There are well defined *Frost Spots* or *Frost Localities*. They are often places where cold air accumulates, such as hollows, valleys and the bottoms of slopes. Early frosts in autumn are also liable to do damage when they occur before the plant has settled down into its winter condition. (*See:* Protection against Frost, p. 130.)

The Growing Season.—The length of the growing season depends firstly on the inborn characteristics of the individual species and secondly on the climate. Certain trees, such as the larch and birch, break into leaf early, others again, like the ash, late. The actual time of opening of the buds is influenced by the temperature, and the time of leafing of a given species may vary considerably over a series of years, according to the early or late occurrence of warm weather.

In some parts of the world, the growing season is much more dependent on moisture than on temperature. This is most obvious in the *monsoon* forests, where the trees shed their leaves and remain in a resting condition during the hot dry season, and resume growth during the cooler rainy season. In such cases, the temperature is adequate for growth throughout the year, but shortage of water acts as a check during certain periods. Even in Europe, the moisture conditions have an influence on the time of autumn coloration and shedding of leaves. These phenomena occur earlier after dry summers than after wet ones.

Trees appear to possess an inherent periodicity of rest and growth, which makes them fitted for particular climatic conditions and is retained by them when they are removed to other climates. Species from a region with a short growing season are unable to take full advantage of the conditions when they are transferred to a region with a long one, because they carry with them their tendency to complete their growth in a short time. On the other hand, species from a habitat with a long growing season are apt to prolong their growth in regions with short

summers and to be caught by autumn frosts before they have completed the formation of their shoots.

Soil Temperature.—The temperature of the soil, in which the roots live and carry out their functions, is just as important for the life of the plant as the temperature of the air. The temperature conditions of the soil not only show wide deviations from those of the air, but themselves vary considerably at different depths. Soil temperatures in general are greatly influenced by the amount of direct radiant heat reaching the surface. For this reason, the temperature of the surface layers undergoes wide and rapid fluctuations, the maxima being especially high. With increasing depth in the soil, however, these extremes are rapidly moderated, so that a few feet below the surface the temperature of the soil fluctuates less than that of the air. As a result the soil, at depths of from two to four feet, is considerably warmer than the air during the whole of the autumn and winter and slightly cooler in the summer. The same is true in a lesser degree of layers from six inches to a foot below the surface, so that the region in which the roots of trees live has a heat climate quite different from that in which the crowns are situated.

Local Climate (Microclimate).—The general climatic conditions of a region are determined by latitude, elevation distance from the sea, etc., but within the region there are differences in the climates of particular sites which are important for plant growth. That such differences in climate exist is common knowledge, and they have their influence on agriculture as well as on the natural vegetation.

In forestry, among the important considerations, is the influence on the climate of the site, of the different aspects of slopes and exposure to different points of the compass of the margins of woods. In these cases, the basic cause of the differences observed, is exposure in varied degrees to the direct rays of the sun. In northern latitudes, a slope facing south receives more solar heat than a neighbouring slope facing north, whilst the eastern and western slopes are intermediate in this respect. Whilst the south slope has the advantage of more heat, it is liable to greater evaporation and the danger of drought is increased. Aspect has also important effects on the water factor by reason of varying exposure to moist and dry winds, rain and snow. In regions where there is ample moisture, and heat is the limiting factor for tree growth, as in high mountains, the forest limit runs higher on south slopes than on north ones, and the same is true of the upper limits of the different species.

The effects of exposure to different points of the compass on the climatic conditions of the margins of woods has been

investigated especially by Chr. Wagner. He described the characteristics of the different wood margins with respect to sunshine and rain and their influence on the form and nature of the ground vegetation, the success of regeneration and the growth of young plants. Whilst in this case, also, it is probable that the differences observed between the various exposures may be traced directly to differences in the moisture conditions, these are, in their turn, largely attributable to varying exposure to the direct rays of the sun. The ecological conditions in the margins of woods and their influence on silvicultural practice will be discussed later (p. 53).

(*b*) LIGHT

The Role of Light in Plant Life. — Light is indispensable to all green plants because it is the source of the energy required for the process of *assimilation*, by which the green leaves obtain carbon from the carbon dioxide gas of the air and utilise it, with oxygen and hydrogen from the water in the plant, to form organic substances of which starch is the first to be easily recognised. As all the other organic substances in the plant are formed directly or indirectly, by all sorts of chemical actions and reactions from the products of assimilation, without light life on the earth would be impossible.

Besides its part in the production of material, light has an important influence on the form and structure of plants, which are modified by the intensity, duration and direction of the light falling upon them.

Whilst all light comes from the sun, it does not all reach the plant in the form of direct sunlight, even when the sun is not concealed by clouds. Much of it is scattered or diffused light from the sky and from objects from which it is reflected. Generally speaking, light in the open is sufficient for maximum assimilation, but where it is reduced by shading, light may become a limiting factor, and the extent to which plants are able to utilise light of lower intensities becomes a vital matter.

In the forest every plant does not receive the whole of the light radiated to a given place, because the members of the community shade each other to a greater or less extent. Even in the open all parts of the plant do not receive an equal share of the light falling upon it. Plants, including trees, differ widely in the amount of shading they will stand, and they are able, to a greater or less extent, to modify the position and structure of their various organs, so as to make the best use of the light available. These modifications are induced by the light itself, which acts as a stimulus, and their extent and efficiency have

much to do with the relative success of the different species in bearing shade.

Relative Light Demands.—The relative demands for light of different species of trees have long been recognised in forestry and the lists of species in the order of their demands for light, drawn up by various authorities, agree fairly well with each other. The approximate order of the common European forest trees in this respect is as follows, beginning with the species requiring most light:—

Larch, Birch
Scots pine, Aspen
Pedunculate oak, Sessile oak, Ash (?)
Sweet chestnut, Common alder, Austrian pine, Weymouth pine
Lime, Sycamore
Spruce, Hornbeam
Beech, Silver fir
Yew.

The species standing at the head of the above list, down to and including the ash, are classed as *Light-demanding Species* or *Light Demanders,* those at the end of the list from the Spruce onwards, as *Shade-bearing Species* or *Shade-bearers,* whilst the remainder may be called *Moderate Shade-bearers.* This nomenclature is in accordance with the fact that all trees, even the shade-bearers, grow more satisfactorily in full light and the differences between them are due to the greater ability of shade-bearers to tolerate lower light intensities.

A wood of light-demanding trees is more open and lets more light in, than a wood of shade-bearers, because the lower and inner twigs and branches, and the more backward individuals perish under much brighter lighting conditions than is the case with the more tolerant shade-bearers. Even when growing in the open, the crown of a light-demanding tree is lighter and less heavily foliaged than that of a shade-bearer. As a result light-demanding trees not only bear less shade, but also cast less shade than do shade-bearers, so that, as a rule, the latter can grow more or less successfully under the cover of the former but not *vice versa.*

It should be noted, however, that the foresters' classification of trees, according to their light demands, has been arrived at chiefly from observation of the growth of trees in woods, and of young plants under the shade of the forest. It must not be overlooked that other factors may contribute to the failure of young trees to survive in such conditions. Fricke and others claim that competition of the roots of the older trees with those of the young plants for water and soil nutrients is the main cause of the failure of young plants under canopies. It has been shown by experiment that root competition has at any rate a considerable

influence, though it has not been proved to exceed that of shortage of light. The results of shading experiments, in which root competition is eliminated, show that there is a considerable amount of agreement between the shade tolerance of species and their behaviour under canopies, so that it seems that lighting conditions, if not the only ones operating, are among the most important in determining the success or failure of species in such circumstances.

The shade-tolerance of young plants, particularly seedlings, is greater than that of older trees, and this is markedly the case with the ash, which as a seedling appears to be the most shade-bearing of our common forest trees, but later on requires a very considerable amount of light. This greater tolerance of young plants is in accordance with the conditions found in nature, where young seedlings start life under the shade of their mother trees and afterwards attain fuller light. Old woods, especially of light demanding trees, tend to become open. Whether this is due to increased light-demands, or whether or to what extent, root competition and other circumstances are responsible is not clear.

Adaptation of Tree-form to Lighting Conditions. — As has already been mentioned, lighting conditions affect the form and structure of trees. The tree has to make the best of the light available and the light-induced modifications contribute towards this end. As a rule, plants, including trees, have their leaves so arranged as to present their largest surfaces towards the direction from which the brightest light comes. Such foliage is said to be *euphotometric*. This condition is found more particularly in plants growing in the shade of the forest, including young forest trees, such as beech and silver fir. As a rule the strongest light comes from above, so that the leaves are held horizontally, but where it comes from the side, as at the edge of a wood, a transition towards the vertical in leaf position may be observed. Sometimes the foliage of plants appears to avoid direct sunlight, by turning the leaves or halves of leaves, with their edges towards the source of light. The foliage of many forest trees, in the upper and outer parts of the crown is of this type, whilst that of the lower and more shaded parts is of the euphotometric type. Some trees again seem to be insensitive to the stimulus of light, in so far as leaf position is concerned. The pine, with its needles pointing in all directions, is an example of this.

The influence of light on the form of trees is not confined to its effects on the position of individual leaves. Not only is the growth of a plant in the shade slower, but the relative size and position of its different parts are also affected. The range of modifications is naturally greatest with shade-bearers which are adapted to a wider range of light intensities. A young beech,

grown in the shade of the forest, has its leaves arranged side by side in a *mosaic*, so that they do not shade each other, and the main shoot bends over, sometimes into a horizontal position. In a young silver fir or spruce, the leader becomes very short, whilst the side branches become relatively longer, so that the crown becomes almost umbrella-shaped. In the conifers, the needles on a shade twig are more markedly combed outwards to the sides than in the light twig, which is generally more brush-like. Leaves grown in the light are always thicker and tougher than those grown in the shade and often have a different colour. Shade buds are not only smaller, but have fewer and thinner scales than light buds.

Finally, the internal structure of shade leaves differs more or less markedly from that of light leaves. It is unnecessary to go into detail here, but the differences are much wider in the case of shade-bearers than light-demanders. It is also found that in young plants, all the leaves or needles, even when grown in full light, have more or less the shade structure, whilst those of older trees, even when developed in the shade, show some tendency to light structure. This is in accordance with the greater shade-bearing capacity of young plants as compared with older ones, which has already been mentioned.

These modifications of habit of growth and the structure of the leaves are associated with differences in behaviour with regard to various vital activities. Buds formed in the shade tend to open earlier than those formed in the light, and this tendency is retained even when the lighting conditions are improved after the bud has been formed. Shade leaves are able to assimilate better in low light intensities than light leaves, but are unable to make such good use of higher light intensities. Moreover, too intense light injures leaves not adapted to it. The shade habit of growth, with its physiological effects, tends to persist after full light is given. Arnold Engler found that some shade-grown beeches showed the horizontal development and overhanging leader characteristic of such plants even six years after transference to fully lighted sites.

(c) WATER

General Importance of Water.—Water is indispensable for plants in several ways. Firstly, it is an essential food material, because it is the source of all the hydrogen which is a constituent element in most of the substances contained in the plant and of which its tissues are built up. Water is also necessary for the life activity of the protoplasm, which can only function when in a saturated condition. It also acts as a solvent for materials in the tissues of the plant and provides the vehicle by

which they are transported from place to place. Finally, it serves to sustain the *Transpiration Current* which, starting from the roots, carries the necessary mineral substances, dissolved in the soil water, to the leaves, where most of the water is given up, in the form of water vapour, chiefly through the adjustable stomata.

The Water-economy of Trees.—By far the greatest proportion of the water taken in by the tree is evaporated again from the leaves. It has already been stated that the force which is largely responsible for keeping the transpiration stream in motion is that of evaporation, which draws water from the leaves, and it is evident that, for the tree to grow successfully, it is essential that a proper relation should exist between the emission and intake of water. This relation depends on both internal and external conditions. The external conditions are those affecting (1) evaporation and (2) the amount and availability of water in the soil. The internal conditions include (1) the extent to which the tree can control evaporation from its own organs, (2) the efficiency of its roots in absorbing water, (3) the efficiency of its internal conducting system and (4) the inherent nature of the plant, including such things as the resistance of the protoplasm and the various tissues to dryness, provision for storage of water for use in times of scarcity, and in general all those internal qualities and adjustments which determine the amount of water required in order that it may carry out its necessary vital functions.

The rate of evaporation depends primarily on the *Relative Humidity* of the air in contact with the evaporating surface. By relative humidity is meant the proportion which exists between the actual amount of water vapour in the air and the amount which it is possible for the air to contain at the temperature existing at the time. The higher the temperature, the greater the amount of water vapour the air can contain. If, therefore, the amount of water vapour in the air remains constant and the temperature rises, the relative humidity falls. The lower the relative humidity, the more rapid is evaporation. Evaporation, by adding to the water vapour in the air immediately in contact with the evaporating surface, increases its relative humidity and is slowed down in consequence. If, however, the air is in motion so that new bodies of air are constantly being brought into contact with the evaporating surface, the local rise of relative humidity does not persist and evaporation continues unchecked. This is the reason why *wind* promotes evaporation. In general, therefore, evaporation is greatest in warm weather, in dry localities and in windy sites.

Sources of Water.—The immediate source from which trees draw their supplies is the water in the soil. This, as well as the moisture in the air, depends greatly on the precipitation, in the

form of rain, snow, dew, hoar frost and mist. Part of the precipitation flows off the surface into streams and part is evaporated without penetrating into the soil. The remainder soaks into the soil and is partly held round, in and between the soil particles, forming the so-called *soil water* from which the roots draw their supplies. The surplus sinks by gravitation to greater depths and accumulates above impermeable strata, forming the *ground water*, which may move off laterally and reach the surface elsewhere as springs. When the ground water is near the surface, it may, by rising under the action of capillary forces, serve to replace water withdrawn from the soil by evaporation or by the transpiration of plants.

The amount of water actually retained in the soil depends, not only on the amount of precipitation, run-off and evaporation, but on the constitution and structure of the soil itself. These vary greatly from place to place, often within quite short distances. Moreover, rainfall and evaporation are affected by aspect, elevation and exposure. For these reasons there are wide local variations in moisture conditions which are of great importance in Forestry.

It is not the absolute amount of humidity in the environment which determines whether a locality is wet or dry from the point of view of plant growth. Physiological dryness is not the same as physical dryness. Physiological dryness is the result of the combination of all the factors which decrease absorption and promote transpiration. The same amount of water in the soil may be sufficient to supply the requirements of plants if the conditions check transpiration, but insufficient if high temperatures and dry winds increase the demands. Moreover, absorption may be reduced, not only by absolute shortage of water, but by low temperature, high concentration of salts in the water, slowness of movement of water in the soil, etc.

Adaptation of Plants to Moisture Conditions.—Different species of plants, including trees, are adapted to different moisture conditions. Botanists call those plants which are adapted to localities which are physiologically wet—*Hygrophytes*, and those adapted to physiologically dry sites—*Xerophytes;* the two forms being connected by gradations. The external conditions affecting evaporation and supply of water in a given locality may vary considerably from time to time. In most parts of the earth there are regularly recurring dry and wet seasons of the year, and the distribution of rainfall and temperature are reflected in the nature of the vegetation of the region. The plants are adapted to the prevailing conditions, but owing to the local variations in soil, etc., some plants succeed on certain sites and fail on others.

The control of plants over transpiration is exercised chiefly by means of the stomata, which are often capable of being closed when the plant begins to lose more water than it can take in. When the stomata are closed, the evaporation of water goes on mainly through the cuticle of the leaves. In xerophytes, the cuticle is generally thick and often covered with felted hairs, waxy deposits, etc., so that when the stomata are closed, very little evaporation goes on. In the case of hygrophytes, however, the cuticle is thin and unprotected, so that the plant continues to lose water by evaporation, it may be to such an extent as to lead to injury and even death in dry periods.

It should be remembered, however, that besides providing for the emission of water vapour, the stomata are the means of intake of the carbon dioxide required for assimilation. When they are closed, assimilation stops. It is, therefore, an advantage for a plant, on a periodically dry site, to be able to assimilate as actively as possible when the opening of the stomata is safe. It is not surprising, therefore, that xerophilous plants are often found to transpire vigorously when supplies of water permit, and to require considerable amounts of water during the growing season. Our conifers have small, hard needles with a thick cuticle and protected stomata, but most of them require considerable moisture for their success. The xerophytic structure is explained by the physiological dryness of the winter season, when low temperatures and the freezing of the wood and soil check absorption, whilst evaporation in dry winds still goes on. Our deciduous broad-leaved trees, when in leaf, are more or less hygrophytic in structure. They are adapted to comparatively moist conditions in the summer. Against the physiologically dry winter season they are protected by shedding their leaves. Plants which change their nature periodically to meet variable moisture conditions are called *Tropophytes*.

The form of the leaves and the mechanism possessed by the plant for controlling evaporation are, however, not the only characteristics which determine its suitability for physiologically dry or wet conditions. The water relations of plants are complicated, and an efficient root system and drought resisting internal properties may help in adjusting supply and demand. Among our forest trees, the Robinia or False Acacia, with its thin, finely-divided leaves, has, during the summer, all the external characters of a hygrophilous tree. Yet it succeeds on comparatively dry sites. It is able to obtain sufficient water by means of a well developed root system of high absorptive power, from the moisture dispersed in a large body of soil.

In the course of its development, a tree grows in such a way that there is a suitable balance between the crown and root

system, so that the roots are able to provide the crown with an adequate supply of moisture and the plant does not lose more water than it can take in, in the ordinary conditions to which it is exposed.

Extremes. — Excess of water in the soil is injurious to all our trees, especially if long continued. As the plant does not take in more water than it actually requires, it is probable that the injury is due, not to excessive moisture as such, but to harmful secondary effects, such as the exclusion of air from the roots, which require oxygen for their respiration, or possibly to the production of poisonous substances in the water-logged soil. Some trees are able to stand a considerable amount of water in the soil, but even the alder, which can grow in very wet sites, does so much better if the water is moving or if periods of flooding alternate with periods of freedom from excessive water. The pedunculate oak can stand occasional flooding, but the sessile oak is very intolerant. Most poplars and willows, and the American grey ash, are among the species which stand occasional flooding well. The majority of trees, including all the conifers, are much more sensitive. Excessive water in the soil results if the ground-water-level is at or near the surface and natural drainage is not sufficient to remove the surplus quickly enough. Such conditions are most common in districts with high rainfall, where evaporation is small compared with precipitation.

Shortage of water is a much more frequent cause of injury than excessive moisture. In fact, water often becomes the limiting factor for plant growth. The approach to the minimum is generally shown by the wilting of the foliage, followed by the death of parts or the whole of the plant. The surface layer of the soil undergoes greater fluctuations in moisture than the lower layers, hence, with forest trees, young plants, with their shallow roots, are more frequently injured by drought than older trees. It is seldom that large trees actually succumb, but they may suffer a serious check in their growth, and investigation has shown that very considerable aggregate losses in timber production in European forests have resulted from the occurrence of a series of dry years. Sometimes even older trees are killed by exceptional droughts. In Europe the spruce, with its shallow root system, is the species which suffers most. Drainage operations, which lower the ground-water level, where it was previously near enough the surface to affect soil moisture, may lead to the death even of large trees.

Local Moisture Conditions.—It has already been stated that, besides the differences in general moisture conditions in whole regions, there are great variations from place to place even within limited areas. These are often due to the local topo-

graphy—gradient and aspect of slopes, elevation, exposure, etc., but there are also considerable variations due to differences in the soil and subsoil. The finer the particles, the more moisture will the soil retain, and the presence of organic matter also increases the water holding capacity of the soil.

Moisture Requirements of Different Species.—It is impossible to measure directly the consumption of water by large trees, and the validity of estimates made by applying figures obtained by controlled experiments on young plants, to woods growing in natural conditions is open to serious question. It is certain that trees are able, with narrower or wider limits, to adjust their consumption to the supplies actually available. Nevertheless, experience of the growth of different species in moist and dry sites has led foresters to recognise that, whilst all trees are grateful for ample water, so long as it is not excessive, they differ widely in their tolerance of conditions which deviate from the optimum in either direction. The lists of European forest trees in the order of their demands for soil water, drawn up by different authorities, do not agree in all respects, especially as regards the species occupying the medium positions. This is, however, of little importance. The following groups may be distinguished :—

I. Small moisture demands : Pine, *Robinia*, Birch, Aspen.
II. High moisture demands : Common Alder, Ash (except on calcareous soils), Poplars (except Aspen), Willows, Spruce, Pedunculate Oak.
III. Medium demands : the other species.

(d) CARBON DIOXIDE

Importance of the Carbon Dioxide Factor.—About 40 per cent. of the dry weight of wood consists of carbon, and this element enters the composition of all the organic compounds in the plant. The source from which trees obtain their supplies is the carbon dioxide gas in the atmosphere. Up till recently little ecological importance was attached to carbon dioxide, because it was thought that the average concentration of this gas in the atmosphere, 0·03 per cent., did not vary greatly, and it was known that, in otherwise favourable conditions, assimilation could be carried out quite rapidly even with this low concentration. Recently, however, more attention has been paid to the subject. That considerable increases in the rate of assimilation can be produced by increasing the concentration of carbon dioxide above the mean of 0·03 per cent. has been proved by experiment on agricultural and forest plants. Whether the changes in concentration found in nature are sufficient to make any appreciable difference in this respect is still a matter of controversy.

Sources of Carbon Dioxide.—The principal sources of carbon dioxide are the burning of coal and wood and the respiration of men, animals and plants. The greatest part seems to be played by the lower organisms, bacteria and fungi, in the soil, which bring about the decomposition of the plant debris and humus and convert the organic carbon into inorganic carbon dioxide. This so-called *soil respiration,* which has often been measured, appears to provide to a great extent for the replacement of the carbon dioxide used up in such large quantities by assimilation.

Owing to the great production of carbon dioxide in the soil, the proportion of this gas in the soil air is much higher than in the free atmosphere. The proportion increases with the depth in the soil. It depends very much on aeration, and when this is bad, the level of 1 per cent., at which toxic effects may set in, is reached even at a depth of six inches or so. The importance of aeration of the soil for the healthy growth of tree roots has already been mentioned.

(*e*) THE WIND

Wind and Transpiration.—Transpiration is promoted by motion of the air, since the partially saturated layer in contact with the leaf surface is removed and replaced by a fresh one. A very gentle movement, however, is sufficient for this and movements sufficiently pronounced to be called wind soon exceed the optimum and transpiration is over promoted; incipient drying then leads to the closing of the stomata to a greater or less extent, with a resulting fall in assimilation. All plants are, however, not equally sensitive. The sinking of the stomata of certain conifers below the surface of the leaf minimises the drying effect of the wind and so permits of continued assimilation in conditions which, in some other trees, would bring it to an end. Some species are unable to completely close their stomata, or have a thin and unprotected cuticle and are apt to suffer excessive drying out in windy sites.

Pathological Effects of the Wind. — Besides reducing assimilation, wind can cause injury to leaves and leaf stalks by the constant bending and shaking to which it subjects them. Mechanical injuries are also produced by the rubbing and beating together of needles and leaves on individual twigs. On exposed sites, these effects become evident in the bareness and death of twigs and branches as well as by the stunting of growth. On the sea coast and other exposed places, broad-leaved trees have generally a stunted bushy form, with the crown sloping upwards from the windward side. In conifers, a flag-like development of

branches on the side of the stem away from the wind is common, especially with the spruce.

Still greater mechanical injuries, such as the uprooting and breaking of stems, are the result of exceptionally strong winds and will be discussed later under Forest Protection.

The sloping off of the crown canopy of woods towards the exposed margin is well known. It may be due to two causes (1) adaptation to the wind by thickening of stems at the expense of height growth, (2) diminution of growth as a whole due to adverse physiological effects. In less windy sites only the first is in evidence.

Effect of Wind on the Soil.—Besides directly affecting plants, the wind acts on the soil by removing leaf litter and drying the surface. These phenomena are most marked on the margins of woods and on exposed slopes and ridges. Inside the forest the wind is greatly moderated and the covering of leaves checks evaporation from the surface. (See: Protection against Wind, p. 135.)

(*f*) THE SOIL

The study of the nature and structure of soils, how they are formed, the processes which go on in them and their relationships to plant life, is a very important branch of science which has developed enormously in recent years. It is just as essential a basis for silviculture as the study of the physiology and ecology of plants. It has long been recognised that care for the fertility of the soil is a duty which the forester must keep in the forefront in all his activities.

The soil is undoubtedly the factor in the productive power of the forest on which the effects of the forester's activities are most marked. Its nature and condition are influenced greatly by the climate and vegetation, and, as the forester is able to control these to some extent as well as to carry out a certain amount of cultivation, he has it in his power to modify the soil for good or ill. In the main, it must be admitted that his operations are more powerful in causing deterioration of the soil's fertility than in building it up, but for that very reason he should be well equipped with a knowledge of soils in general and forest soils in particular.

Obviously, in a book of this kind, it is impossible to go into the intricate subject of the chemistry and physics of the soil, which should be studied in a special course with practical work in the field and in the laboratory. All that will be attempted is to indicate some of the most important aspects of the relation of trees to the soil and the way in which forestry operations and treatment may influence the soil fertility.

Role of the Soil in Tree Life.—The soil gives the tree stability by affording anchorage for its roots and also provides it with a certain portion of its food. The qualities of the soil which affect its efficiency in these directions are:—

Its Depth.
Its Chemical Constitution.
Its Physical Condition.

The Depth of the Soil

The depth of the soil, that is the thickness of the layer which is permeable by the roots of trees, is important first of all because it affects the stability of the tree. Shallowness of the soil need not necessarily be due to the presence of solid rock, or even a hardened layer such as moor pan, near the surface. The downward penetration of the roots may be limited by the occurrence of ground water or by insufficient aeration. In such cases the soil is said to be *physiologically shallow*. Species of trees differ in the depth to which they naturally seek to send their roots, so that a soil which is deep enough for one species may be too shallow for another, as it causes a crippling of the natural root system. Naturally deep-rooted trees, growing on shallow soils, are often subject to wind throw. Species which normally develop a shallow root system, on the other hand, may obtain a surprisingly firm hold on rocky soils where their roots clamber over and round rocks and boulders. Some rocks are more fissured than others and give a better foothold for trees. The deeper the normal or natural root system of a species, the deeper must the soil be for it to succeed. All species, even shallow-rooted ones, prefer a deep soil rather than a shallow one.

Shallow soils have other drawbacks besides failing to give a good root hold. They are apt to undergo extreme fluctuations in temperature and moisture, so that they tend to be hot and dry in summer and cold and wet in winter. They have also a smaller store of plant nutrients. These conditions, together with the cramping of the root development, lead to a checking of the height growth of trees grown upon them.

The Chemical Constitution of the Soil

The Soil as a Source of Nutrients. — The soil is the source of certain indispensable plant nutrients. The first and most important of these is *water*, not only because it supplies oxygen and hydrogen, but because none of the other nutrient substances in the soil become available for the roots of plants, unless they are dissolved in water. However rich in mineral matter a soil may be, it is absolutely sterile without water,

whereas if water is abundant, even a poor soil may be more productive than its mineral content would suggest, because quite considerable quantities of minerals are dissolved in the large body of moisture and so become available.

As the roots of the trees require oxygen for their normal activity, *aeration* of the soil is also necessary.

In order that a soil may be productive, therefore, besides the solid material, there must be a liquid constituent, the soil water with the substances dissolved in it, and a gaseous constituent, the soil air, which differs from the free air chiefly by having a higher concentration of carbonic acid gas.

The bulk of the material in most soils consists of the products of the physical and chemical weathering of the rocks which form the earth's crust. It consists of particles of varying size and composition and forms the so-called *Soil Mineral Matter*. In addition soils contain material which results from the decomposition of plant and animal substances which have originated on or near the surface—the *Soil Organic Matter* or *Humus*.

The Mineral Constituents of the Soil. – The mineral particles may vary in size from pebbles and gravel down to the sub-microscopic particles of colloidal clay. They are the products of the physical and chemical weathering of the rocks. For purposes of investigation it is customary to reject all fragments over 2 mm. in diameter. They are, for the most part, unaltered fragments of the original rock. The larger particles that remain are mainly fragments of the rock-forming minerals (*e.g.* quartz, felspars, mica, etc.), the residual products, resulting from the disintegration of the rock by the weathering processes. The very small particles which form the so-called *colloidal clay* are the products of chemical weathering. They are the active constituents in the mineral soil. The larger particles are, to a great extent, chemically so inert, that their immediate importance as sources of available plant nutrients is negligible by comparison. Through the continual operation of the weathering processes, they add, however, though generally very slowly, to the quantity of the colloidal material and to the available mineral nutrients. The immediate importance of the medium and large particles in the soil is chiefly physical.

The colloidal clay has certain physical properties which affect the water and air conditions in the soil. The particles retain water powerfully by imbibition and soils which contain a considerable proportion of clay have a high water holding capacity and the water is retained within the particles themselves. Clay swells on wetting and shrinks on drying, it is plastic when moist and gives the soil cohesiveness or binding qualities. The particles of colloid clay may be present as independent aggregates or as coatings of

the non-colloidal particles. They confer on the soil the power of *flocculation* and *deflocculation,* that is of having its particles aggregated together into clumps or crumbs, or dispersed as individual grains. The possession by a soil of a crumb structure is highly important for the movement of water and air in it. The wider spaces between the crumbs do not remain filled with water held by capillary forces so that there is space for aeration, whilst the narrow interstices between the particles in the crumbs themselves retain water well.

One of the most important properties of the colloid particles is the power they possess of abstracting certain substances from their solutions and holding them in a sort of loose union which leaves them still available for the nutrition of plants. The chemical relations between the colloids and the soil solution are too intricate to be discussed here. It is only necessary to say that the presence of excess of acid in the soil tends to liberate the bases adsorbed by the colloid particles, which are then washed down into lower layers in the soil (leaching) or removed in the drainage water. Such acid conditions of the soil are often produced by certain kinds of humus formation, especially in cool, wet climates.

Soils which contain a high proportion of clay are often rich in mineral nutrients, but their physical condition may be unfavourable to the movement of water and especially air.

It was formerly thought that the fertility of a forest soil was mainly dependent on its total content of mineral plant nutrients. While there is a certain amount of truth in this in the case of certain sandy soils whose mineral content is low, in loam soils the minerals are sufficiently abundant for small differences in them to have little effect, and other conditions, *e.g.* the water factor, are much more important. In any case, the mineral content of the soil is much less important in forestry than in agriculture. Trees withdraw from the soil far less mineral matter than do agricultural crops and they are harvested at much longer intervals. The quantity of mineral matter withdrawn from the soil by a crop can be estimated from an analysis made of the ash which remains after the material is burnt.

The Mineral Content of Trees and their Demands on the Soil—Numerous analyses have been made of trees and their parts, and though they do not always agree in detail the general results are similar. The following figures, quoted by Dengler from Wolff's "Aschenanalysen," give the average mineral content (pure ash) of certain trees and agricultural plants in parts per 1,000 of dry matter :—

TABLE I

	Leaves o/oo	Young 1-4 yr. plants. o/oo	Small twigs. o/oo	Wood of old stems o/oo
Beech	50–70	27	14–18	3–4
Oak	40–50	—	17–18	2–3
Birch	—	—	7	3
Pine	19	26	12	3
Larch	36	—	—	2
Spruce	26	27	—	2–3
Silver fir ...	33–37	—	—	2–3

Meadow hay 70 o/oo, Wheat in ear 97 o/oo, Potato tops 86 o/oo, Stinging nettle 135 o/oo.

The above figures bring out the small ash content of forest trees as compared with agricultural crops and also the very small content of stem timber as compared with twigs and young plants and especially leaves. The leaves have by far the highest proportion of minerals, but even they are considerably poorer in ash than the agricultural plants. The needles of conifers are poorer in ash than the leaves of broad-leaved trees.

These figures are significant, but they do not give a complete idea of the relative draft on the soil of forest and field crops, because the total quantity of material produced has also to be taken into account. In the forest the timber accumulates for many years and is removed at long intervals, whilst the field crops are harvested annually. Schröder has calculated the amount of mineral matter (pure ash) permanently withdrawn from the soil in average conditions by crops of the following trees, in lbs. per acre per annum :—

TABLE II

	Pine lbs.	Spruce lbs.	Silver fir lbs.	Beech lbs.
Total ash	11·66	21·07	19·22	38·73
Potash, K_2O	1·86	3·64	8·25	6·38
Lime, CaO	6·84	9·13	3·67	19·83
Magnesia, MgO	1·28	1·76	2·50	5·13
Phosphoric acid, P_2O_5 ...	1·00	1·45	1·25	3·77
Sulphuric acid, SO_3 ...	0·20	0·61	1·16	0·29
Silica, SiO_2	0·47	4·49	1·38	3·33

Ebermayer gives similar though not identical figures for the mineral consumption of forest crops and also figures for that of agricultural crops, which enable the following comparison to be made between the average annual consumption per acre of the principal European forest trees and the principal agricultural crops:—

TABLE III

	Total ash lbs.	K_2O lbs.	CaO lbs.	MgO lbs.	P_2O_5 lbs.	SO_3 lbs.	SiO_2 lbs.
Forest crops...	19	4	9	2	1·4	0·4	1·6
Agricultural crops...	235	78	43	17	28	11	37

The figures given for forest crops refer only to the mineral content of the wood, and trees actually take in considerably more mineral materials every year, but the excess is returned to the soil annually or after a short interval, by the fall of leaves, flower parts, twigs, bark scales, fruits, etc., and generally only the timber is permanently removed from the forest. From the above figures it appears that the forest requires far less mineral matter than the average field crop, if the permanent drain on the soil ingredients is considered. The current requirements of the forest, for the production of wood, leaves, rind, etc., are of the order of one half of those of the average field crop, but the bulk of this is lime, and on the average, the forest requires only about one-seventh as much potash and two-sevenths as much phosphoric acid as field crops, for current requirements and only about one-twentieth as much of these rarer constituents is permanently withdrawn from the soil by the forest.

Broad-leaved trees make greater demands on the soil minerals than conifers, and, as will be seen from the figures in Table II, the requirements of the different species for the various minerals are not the same, so that mixed crops will utilise the mineral resources of the soil more fully than pure crops of any one species.

The demands of forest trees on the mineral nutrients in the soil is so small that practically all soils contain sufficient provided the leaf mould (humus) is not removed. If, however, the litter is regularly taken away for a long period, any but the most fertile soils are likely to become exhausted, just as the soil of a field does if the ingredients removed are not replaced by manuring. The removal of leaf litter also interferes with the supply of *nitrogen* in the soil (see p. 40) and, if long continued, has harmful effects also on its physical condition.

The Humus or Organic Matter in the Soil.—Humus is organic matter in process of decomposition. It originates from the plant debris falling on the soil—the *litter*—as well as from dead stems, roots, etc., of plants growing on the surface, and also, to a much smaller extent, from animal remains and excreta. In the forest the quantity of such material is especially great and its effects on the soil correspondingly important.

Humus affects the soil in various ways. Carbon dioxide, formed during the process of humus formation, dissolves in the soil water and helps in the solution of carbonates, phosphates and silicates in the mineral soil. Besides this, however, the considerable quantities of mineral matter in the organic debris are liberated in forms which are available for the nutrition of plants. Humus therefore enriches the soil in these two ways. Moreover, the liberation of mineral matter in the humus, owing to the

rapidity of its decay, is much quicker than the extremely slow processes of weathering in the mineral soil, especially in cool, moist climates.

Unfortunately, in such climates, the beneficial effects of humus in enriching the soil are more or less seriously offset by the constant washing out (leaching) of the soluble constituents from the upper layers of the soil. The amount of such leaching is, however, dependent on the way in which the humus is formed and the course of its decomposition.

In addition to its effects on the mineral supplies, the humus is the main source of the *nitrogen* in the soil. With the exception of a few species which, in symbiosis with certain bacteria, are able to utilise the free nitrogen of the air, all the higher plants, including most trees, depend for their nitrogen on the dissolved nitrates and ammonium salts in the soil. The *Robinia* and the two species of alder, with their bacteria-containing root nodules, are the only known exceptions among European forest trees. There are no rocks or minerals which contain a store of nitrogen which can be made available by the weathering processes, so that the forest depends entirely on that stored or produced in the organic matter in the soil.

The organic debris which is produced or deposited on the surface of the soil contains nitrogen as a constituent of complex organic compounds. In this form the nitrogen is not available for the roots of plants, but in the course of humus formation and decay these compounds are broken down and the nitrogen appears in the form of ammonium salts, nitrites and nitrates, which can be utilised again by the vegetation. This process is the result of the activity of fungi and bacteria in the soil. The nutrition of trees by nitrogen involves therefore a cycle in which the element is taken from the soil by the roots, used in the life processes of the tree to form various organic substances, returned to the soil in the litter, undergoes transformation into forms which are suitable for the trees to absorb and goes through the whole process again. In this cycle the humus and the micro-organisms responsible for its formation and decay form a vital link. If the cycle is broken, either by the removal of the litter before it is decomposed (collection for use in agriculture, blowing away by wind) or if its decomposition is hindered or stopped (formation of peat or raw humus) owing to unfavourable life conditions for the micro-organisms, the supply is interrupted and fertility is reduced. The existence of the *Nitrogen Cycle* does not account for the upkeep and the actual increase of the store of combined nitrogen which takes part in it. A certain amount of ammoniacal and nitrate nitrogen is contributed by the rainfall, but the activity of nitrogen-fixing bacteria which live in the humus is probably more im-

portant. These organisms are able to utilise the free nitrogen of the air for the formation of organic compounds which are easily decomposed into the simpler forms which are available for the nutrition of the higher plants. Against these gains in the store of combined nitrogen in the soil must be set the losses due to the carrying away of soluble nitrogen compounds in the drainage water and to *denitrification* whereby, under certain conditions, free nitrogen is liberated. There are also, of course, the losses due to the withdrawal of supplies of nitrogen in the crops removed or, in the case of trees, locked up for long periods in their wood.

Mycorrhiza.— The roots of many forest trees are found to be constantly in association with filamentous fungi, and it was for a long time a question whether the nutrition of the tree with nitrogen was in some way dependent on such an association. The researches of Elias Melin, who was the first to succeed in infecting tree roots with a number of fungi raised in pure cultures, showed that there were various kinds and degrees of association between the fungus and the host plant. Melin distinguished between *true mycorrhiza* with which mutual promotion of growth (true symbiosis) occurred, and *pseudo-mycorrhiza,* which caused injury (parasitism). Much more work remains to be done in this field, but it appears that soil conditions influence the nature of the association. So far as research has gone, it seems that the mycorrhiza do not fix free nitrogen, but that in certain unfavourable forms of raw humus, the fungus converts the complex nitrogenous compounds, which are not available for the ordinary roots of trees, into ammonium compounds from which they can obtain their supplies of nitrogen.

Soil Acidity. — Considerable attention has been given of recent years to the effects of the degree of acidity of the soil on plant growth. It appears that soil acidity is much less important for forest trees than for agricultural plants. It is significant, in this connection, that in a forest soil, the upper layers are always more or less acid, whilst with increasing depth, a rapid decrease in acidity occurs, so that a soil decidedly acid in the upper layers, may be very slightly acid or even neutral in reaction at a depth of a foot or fifteen inches. The roots of trees must therefore live in layers of varied degrees of acidity, but, hitherto, no effects on their development due to this circumstance has been observed. The reaction of soils under broad-leaved trees is much less acid than under conifers. Though young seedlings appear sensitive to extreme acid and alkaline conditions in the soil, older trees and woods seem to be indifferent. It is probable that the degree of acidity alone is not an indicator of the fertility of the soil, but that the amount of exchangeable calcium and other bases is the important thing. A soil has an acid reaction if its capacity for

neutralising bases is not saturated. A soil rich in organic matter may have quite a high proportion of exchangeable bases and still be acid in character, whilst one with a low proportion of organic matter, if equally acid, will have a small one.

The ground vegetation appears to be much more sensitive to soil acidity than the trees. Certain forest weeds appear to be confined to soils whose reaction lies within certain limits of acidity, so that it may be possible, after further investigation, to assess the degree of acidity of the upper layers of the forest soil, by the constitution and vigour of the ground vegetation. Finally, the acidity of the soil may have even greater influence on the micro-flora and -fauna of the soil, and owing to the importance of the role played by these organisms, this aspect of the acidity question may in future occupy most attention.

Excessive acidity in the soil is associated with the presence of a peaty, humus layer, and intensifies the process of leaching, by which the bases, lime, magnesia, potash and soda are washed down from the upper layer of the soil in localities where, owing to high rainfall and low evaporation, there is much percolation. The downward percolating water contains humic acids, and a decomposition of the clay complex occurs, whereby ferric oxide and, in some cases, alumina, become mobile, and are removed from the upper horizons and deposited lower down. The result is that an upper bleached layer, the " A " horizon, overlies one in which these sesquioxides accumulate, the " B " horizon. In some cases humus is also deposited at the top of this layer of accumulation. The development of the " B " horizon may proceed to the extent of forming a *pan* which offers resistance to root penetration and may also impede drainage. Such conditions are obviously detrimental to tree growth.

The Physical Condition of the Soil

The physical properties of the soil depend mainly on the proportion of finer and coarser particles and their mutual arrangement (single grained or crumb structure). They govern the heat and water conditions and the aeration of the soil, and these have a more important influence on tree growth than the chemical constitution of the soil.

Heat Conditions. — Heat capacity and heat conductivity depend to a great extent on the water content of the soil. Water warms up more slowly than the solid material of the soil, so that it acts as a cooling agent. Moreover, the evaporation of water from the surface involves a great loss of heat. Clay and peat soils are cold, because of their high water content which causes them to warm up slowly in spring. A clay soil that is dry may

warm up very quickly. These conditions are more important in agriculture than in forestry, because the temperature of the forest soil is much more equable owing to the overhead cover of the trees.

Moisture Conditions. — Soil moisture has already been dealt with under the Water Factor. The retention of water in the soil is the greater, the higher the proportion of the finer particles. A high proportion of humus in the soil increases the water holding capacity because it increases the proportion of finer particles and the humus particles themselves are hygroscopic.

The capillary rise of water in the soil is promoted by the content of fine particles and the closeness of packing of the soil. It is only advantageous where there is a surplus of water in the sub-soil (high ground water table). Otherwise, the continuous movement of the water to the surface, where it is constantly evaporated, will produce unfavourable conditions, and the breaking of the capillarity either by a covering (litter) or by artificial loosening of the surface (cultivation) is desirable. These considerations are important in sandy soils whose water holding capacity is low. In soils rich in the finer particles (loam or clay) water is generally sufficient and it is aeration which plays the more important part in their fertility.

Aeration. — This depends on the structure of the soil. A good crumb structure, in which the soil particles are aggregated together into little groups (crumbs), facilitates access of air and allows of the penetration of the finer rootlets better than a dense, single-grained structure. It also allows rain water to percolate more easily, especially in heavier soils, and hinders evaporation, owing to the poor capillarity of soils in this condition. A good crumb structure of the soil provides the best conditions for the growth and life processes of the vegetation and for the decomposition of organic debris falling upon it.

5. FOREST CONDITIONS

(1) The Forest as a Community

Trees have certain characteristics which give them a dominant position in the plant world. They are long lived, and are capable of attaining a considerable height, so that their crowns, with their masses of leaves, are carried high above the competition of other types of vegetation, while their deep root systems enable them to make use of supplies of water at a con-

siderable depth in the soil, and render them independent of temporary fluctuations in the supply of moisture in the surface layers. The dominance of trees in the plant world is, however only fully asserted when a sufficient number of them are growing side by side, to cover a considerable area—an area at least large enough to ensure that the conditions within it are governed by the trees themselves and not by their surroundings. Moreover, the trees must stand sufficiently close together to form a cover which exercises its influence in all parts of the area. It is this combination of height, density and area which characterise *forest* as a type of vegetation. If the trees are growing singly or in small groups, the intervening ground being occupied by grass or some other form of vegetation, we are no longer dealing with forest in an ecological sense.

As the forest can only exist if there are a large number of trees growing in close order, it follows that it involves the association of individuals into a *community* which can produce conditions and effects which individuals acting separately cannot do. Though trees are the dominant members of the community, the forest is very far from being a mere collection of trees growing on a mineral soil. Other plants and even animals are associated with them. The trees only form the upper layer, which in certain cases may be divided into several sub-layers, under which other plants of lesser height, such as shrubs, herbs and mosses may be present. Even in the soil itself there are immense numbers of bacteria and fungal hyphæ, which play an important part in the life of the community. The animals of the forest may also make important contributions to its life. This is notably the case with the soil fauna, especially the earthworms, whose activity favourably affects the structure and fertility of the soil. Insects, in many forests, especially in the tropics, are essential agents in the pollination of the flowers of the trees.

In the forest community, every individual strives to obtain for itself and its offspring the space and nourishment necessary for life. This involves *competition*. The struggle for existence, which plays such an important part in nature, is exemplified in a most striking manner in the forest. Above ground, it resolves itself mainly into a struggle for *light*. Every tree competes with its neighbours for as large a share as possible of the light falling upon the forest from the sky, by striving to thrust its crown, with its assimilating organs, the leaves, above those of its neighbours. The individuals which fail to hold their own in the struggle are doomed to destruction sooner or later. Their crowns are overshaded, their assimilation drops, and, left behind in the semi-darkness below, they ultimately fail to nourish themselves sufficiently to maintain life.

Owing to the wide-spreading roots of forest trees, competition also goes on in the soil, for water and soil nutrients. The smaller plants, bushes, herbs, mosses, etc., are also involved in competition. While they have, as a rule, to submit to the dominance of the trees, they compete among themselves and with the young progeny of the trees for such light as can reach them and for their share of the moisture and plant food in the soil.

In a true community, however, besides competition there is also *co-operation* between the members. The trees protect and support each other against the wind, their crowns unite to form a canopy which shades the soil and so keeps injurious weeds out of the forest; they protect, by the shelter they give, not only their own but their neighbours' offspring from destructive frosts. They produce, as we shall see, within the forest a climate quite different from that outside and distinctive soil conditions which are almost essential for many members of the community and are, for others at any rate, very beneficial.

The long continued interaction of competition and co-operation tends to produce ultimately a condition of equilibrium in the forest community, which gives it stability and permanence. When this condition is reached, the forest is said to be the *climax type* of forest for that particular locality. The species and their relations to one another best adapted to the conditions of the locality have been established. The climax type is the end of a succession of types of vegetation which may have occupied the site in the past, each of which, by modifying the climate and soil of the site, has paved the way for its supercession by another type. New species have found conditions favourable for establishing themselves and more or less completely ousted the old. The climax type depends on the climate and soil and the particular species of plants and animals which have had an opportunity of entering the community and their actions and reactions on each other. The equilibrium established in the forest community is not static but dynamic—it constantly undergoes fluctuations through variations in the weather from year to year, which favour or discourage certain members or sets of members. There are, however, always compensating factors. Wet years are succeeded by dry years, warm seasons by cold ones; if one set of members multiplies unduly, its enemies also increase and the over-produced species is brought back to normal. The mechanism of the biotic equilibrium is so constructed that it always re-establishes itself provided there are no over powerful or persistent interferences from outside. The most important of these interferences are those for which man is responsible. He has introduced other members into the forest community, such

as new species of trees, grazing animals, etc., and, with axe and fire, has introduced new factors into the environment, favouring some and injuring or destroying other sets of members, with varying effects on the forest, some direct and evident, some of them indirect and not immediately obvious, but, nevertheless, of far-reaching consequence. It is therefore necessary that silviculture should be based, not only on a knowledge of the relationships of the natural forest to its environment, but also of the responses of the forest to human action of various kinds.

Though a certain type of forest may appear to be the climax type of the locality, it is difficult or impossible to determine if it is actually so or not. For practical purposes, it is sufficient if the changes in it are so slow as to have no appreciable influence on its growth or reproduction. The forester will generally not be dealing with climax types, because his operations modify the forest. If, however, he wishes to establish and perpetuate a certain type of forest, the further it departs from the natural forest of the area, the more will he have to interfere to maintain it, and the more difficult will it be to ensure its satisfactory growth, health and regeneration.

The idea that for each locality there is a type of vegetation which will establish itself naturally—in a forest site, a certain type of forest—and that conversely, wherever similar types of vegetation are found, the same ecological conditions exist, is at the basis of the *Systems of Forest Types* by which localities are classified according to the vegetation present on the site. When considered in detail, the natural vegetation varies greatly from place to place, and a forest type is characterised not only by the species of trees, their rate of growth, their form, etc., but also by the nature, vigour and plenteousness of the ground vegetation and even of the soil micro-organisms. All of these vary with the infinitely varied conditions from place to place, even within short distances. For practical purposes, however, these detailed variations are not of importance. By selecting certain features in the vegetation it is possible to use them as a basis for grouping together a number of sites whose conditions and whose potentialities for forest growth lie within fairly narrow limits. Cajander, in Finland, has used certain features in the ground vegetation as a basis for his classification of forest types, ignoring the tree species. In forests, subject to human interference, it is claimed that the tree population is more altered than the ground vegetation and that the latter forms a better index of the soil conditions. Cajander therefore classifies sites by means of certain indicator plants in the ground vegetation. The merits and limitations of this system are still matters of discussion.

(2) The Effect of the Forest on the Climate and Soil

(a) HEAT CONDITIONS IN THE FOREST

The close canopy of the forest intercepts the greater part of the radiant heat of the sun. It also shuts off, to a certain extent, the space beneath it from the free atmosphere above and interferes with the free circulation of air between them. The extent to which these effects are produced depends on the completeness of the canopy and this, in turn, depends on the density of the individual crowns and the closeness of the trees to each other.

Forest Soil Temperatures. — The result of the holding back back of the heat rays by the canopy is that the soil is warmed up more slowly in the forest than outside, and this applies also to the layer of air immediately in contact with it. Measurements over a series of ten years have shown that the mean temperature of the soil in the forest, down to a depth of about four feet, is lower than that of the soil outside, during the whole of the summer half of the year. The layers nearest the surface show the greatest differences. On the other hand, the canopy checks the radiation of heat from the soil in cold weather and the forest soil is warmer in the winter half of the year than the soil in the open. Though the differences in the mean temperatures are small, the effect of the forest on the extremes is more striking. In certain European forests, the soil in the main root region was found to be 4-5 deg. C. cooler on the hottest days and 1-2 deg. warmer on the coldest days, than the soil outside the forest. Frost therefore does not penetrate so deeply in the forest soil. The soil climate of the forest is thus more *oceanic* in character than that of the open ground. Though the actual differences are small, their importance should not be underestimated, because of their continuous and persistent action.

Air Temperature in the Forest. — Many experiments have shown that the forest exercises a similar modifying effect on the air temperature to that which it does on the soil. As a result, the soil micro-organisms, the ground vegetation, young reproduction and the underwood, live in a climate which is somewhat cooler but more equable than the mother crop.

As these modifications of the heat climate are due to the presence of the canopy, their magnitude depends on the closeness and density of the latter. It is therefore not surprising that under species with somewhat open crowns (pine, larch, birch) the differences are always small, under those with a permanently dense, evergreen crown (spruce, silver fir) always large, and

under deciduous broad-leaves tree with heavy foliage (beech) great in summer and small in winter.

(b) LIGHT IN THE FOREST

It is obvious that the presence of the canopy greatly reduces the light in the space beneath. The reduction in the intensity of light beneath a canopy depends on the species, and especially on the shade-bearing capacity of the species. The greater this, the denser will the foliage of the trees be. The ground flora and the lower members of the community will, however, have to endure even more shade than the lower leaves of the crowns, because the branches and stems also cast shade. Even before leaf break, the light intensity in a 70 year old beech wood near Vienna was found by Cieslar to be only 25 per cent. of that in the open. The light intensity in the same wood in full foliage on a bright July day was only 6 per cent. of that in the open. Even smaller light intensities have been found under spruce and silver fir. It is not surprising, therefore, that the lighting conditions have a great effect on the ground vegetation in the forest. With increased light, not only does the ground vegetation increase in vigour of growth and abundance, but the number of species also increases. Naturally these effects are not due entirely to alterations in light; other factors contribute. (See p. 25.)

The degree of lighting in the forest also influences the appearance of natural reproduction and its establishment. The gradual opening up of the canopy in mixed woods results in the appearance of young growth in order of shade tolerance: *e.g.* first silver fir or beech, then spruce and, finally, pine or birch. The abundance and composition of the ground flora is often a valuable index of the lighting conditions in the forest and a guide for the regulation of the light for the promotion of regeneration.

(c) WIND IN THE FOREST

Inside the forest the velocity of the wind is reduced most markedly in the region of the crowns. Near the ground there is a second marked breaking effect, not so great as the first. The reduction of wind velocity in the stem region depends on the constitution of the wood. When the crowns are in one layer carried high above the ground the slowing down of the wind is much less than where the crowns are at varied levels as when an underwood is present. A wood forms an obstacle to the passing of the wind over the surface of the land. A horizontal wind striking the edge of a wood is forced to rise and pass over the tops of the trees, descending again on the lee side of the

wood and reaching its original velocity at a comparatively short distance from it. The distance to which the effect of the wood in reducing the velocity of the wind on the leeward side extends, varies with the height of the wood, its density and the lie of the land. Few researches have been made into the distance to which protection from winds is given by the presence of a neighbouring wood. It appears that it is inconsiderable beyond a distance of 300 ft.

(*d*) WATER CONDITIONS IN THE FOREST

Precipitation in the Forest.—The crown canopy of the forest intercepts the precipitation and prevents it, to a greater or less extent, from falling direct on the ground. A considerable amount of the rain- and snowfall, however, ultimately drips from the foliage or trickles down the stems to the soil, but part of it is evaporated directly from the crowns and never reaches the soil at all. The proportion of the total precipitation thus lost to the soil varies considerably according to the species, the closeness of the crop and the nature of the precipitation. Trees with dense crowns intercept more than those with open ones and the deciduous broad-leaved trees are more effective in this respect in summer, when in leaf, than in the winter conditions. Light showers of brief duration are more completely intercepted than heavy or prolonged rains. Precipitations of less than 1 mm. practically do not reach the soil of the forest at all. The following figures (averages for a number of experimental stations) give the proportion of precipitation held back by the crowns: larch 10-15 per cent., beech 25-30 per cent., spruce 25-35 per cent. These figures include the amounts which ran down the stems, but according to Hoppe, this is considerable only with broad-leaved trees with branches directed upwards, especially the beech, where it may reach 10 per cent. or more, whilst with the spruce it is hardly 1 per cent.

Atmospheric Humidity in the Forest. — Experiments seem to indicate that, while the *absolute* proportion of water vapour in the air in the forest does not differ markedly from that outside, the *relative* humidity is somewhat higher.

Evaporation in the Forest.—The reduced radiant heat and the protection from wind causes evaporation in the forest to be considerably less than outside. Numerous experiments have shown that evaporation from a free water surface in the forest may be 40-50 per cent. less than in the open. The extent to which evaporation from the soil is reduced depends in individual cases on the nature of the surface—whether it is bare, covered with leaf or needle litter on with a ground vegetation.

Soil Moisture in the Forest.—If the presence of the forest cover deprives the soil of about 25 per cent. of the precipitation but reduces evaporation by 40-50 per cent., it would seem at first sight, that the soil in the forest should be wetter than that outside. No account has been taken, however, of the very considerable amount of water withdrawn from the soil by the roots of the trees and transpired into the atmosphere through the leaves. It has already been stated that it is impossible to measure and difficult to estimate the amount of water actually transpired by the forest, but its effects can be seen in the drying of the soil. Examination of the moisture condition of the soil in the forest shows that, with the exception of the surface layer, which is sometimes moister, the layer of soil immediately below the surface are always drier in the forest than in the open. The whole of the soil in the region in which the roots operate thus shows the effects of the draft made by the trees on the soil water.

On the other hand, the forest has a favourable effect on the water economy of steep slopes, as the run-off is better equalised in the forest. The soil is protected from the direct force of heavy rain, and owing to the covering of litter, high humus content and greater water holding capacity of the forest soil, a greater proportion of the water soaks into it and descends the slope through the soil itself (see p. 29) than is the case in the open. After long continued rain, when the soil is thoroughly soaked, the difference disappears, but the moderating effect of the forest on the supplies of water to streams and rivers is, in some cases, of great importance. The destruction of the forest cover in mountain regions has led repeatedly to erosion of the soil and to disastrous floods. When the forest has once been destroyed and the finer soil washed away, the re-establishment of the forest is very difficult and may call for costly and elaborate engineering works to fix the ground and control the torrents. Such works have been considered necessary in the interests of the inhabitants of the lands affected and have been carried out at great expense to the State, in parts of France, Switzerland and India.

The afforestation of water catchment areas is advocated on the ground that, by holding up the water falling on them and parting with it more slowly, the forest makes supplies to the reservoirs more regular. They will continue even in periods of drought, whereas, when the ground is not under forest, the excess water in rainy periods after the reservoirs are filled runs to waste, whilst in dry periods the inflow is much reduced. The forest thus acts, to some extent, as an additional reservoir.

(e) INFLUENCE OF THE FOREST ON THE SOIL

The influence of the forest on the soil is often profound. Forest soil is often quite different from bare soil or arable or pasture soils, even on the same geological formation and under similar external climatic conditions. The effects of the forest on soil temperature, moisture, light, carbon dioxide and wind have already been briefly touched upon when dealing with these factors. With regard to the consumption of minerals, it has already been stated that the forest consumes comparatively little mineral matter, provided the litter and young material are allowed to remain and their conversion into humus proceeds in a satisfactory manner. There may even be an enrichment of the surface layers, through minerals being brought up from lower levels by the roots of the trees and returned to the soil in the litter.

Some idea of how the nature of the material removed from the forest may affect the store of nutrients in the soil may be obtained from the following figures :—

AMOUNT OF CERTAIN MINERALS IN A CUBIC METRE OF MATERIAL—SCOTS PINE

	Potash g.	*Lime* g.	*Phosphoric Acid* g.
Timber (old wood)	166	683	69
Brushwood (young twigs) ...	793	2150	626

Allowing the comparatively worthless brushwood to remain in the woods, reduces the drain on the soil nutrients appreciably.

Unlike the primeval forest, the cultivated forest does suffer an actual drain of materials which tends to impoverish the soil. Whether this drain is likely to lead to a diminution of soil fertility or whether it will be offset by additions to the available nutrients by the processes of weathering will depend on circumstances. At any rate, there is no evidence of soil impoverishment in properly managed forests due to exhaustion of any mineral ingredient. The law of minimum, of course, applies to the available soil nutrients, and if any of them are deficient it limits the growth of the forest. Apart from water and air, however, the limiting factor in the soil nutrients in the forest appears to be almost always *nitrogen*, not one of the mineral substances.

Litter and Humus-formation.—It is in the formation of humus from the litter which falls from the trees that the forest exercises its greatest influence on the soil. Large quantities of leaves and other debris fall on the ground every year and are subjected to decay, through all sorts of chemical, physical and biological agencies. If the decay of the humus proceeds rapidly and well, the organic constituents are very thoroughly broken up

and converted into a fine-grained, porous mass, in which nothing of the original structure of the plant parts from which it was formed can be distinguished by the naked eye. This form of humus is known as *mould*. When the decomposition proceeds slowly and badly the humus is apt to accumulate in masses in which large fragments of the debris, whose original structure remains apparent, are still to be seen. The whole mass is generally matted together by fungal hyphæ. If it remains loose in texture it is what is known as *raw humus*, but if the felting is so close that solid masses can be broken out, it is *surface peat*.

Below the layer of surface humus is the humus which is actually in the mineral soil. This may have been carried down by purely mechanical means (rain or burrowing animals), in which case it lies in small granules mixed with the mineral soil, or it may have gone into solution and have been deposited as a coating round the mineral particles.

The most favourable condition is when the litter is so completely decomposed and carried down into the soil in the course of one year, that when the new fall of leaves occurs in the autumn, there is no longer any layer of surface humus on the ground. When decay is not so complete and an accumulation of surface humus takes place, unfavourable effects begin, not only because of the exclusion of air, heat and water from the soil, but often because acid conditions are produced leading to the leaching out of the soil in the upper layers. These layers become impoverished and iron- and other mineral compounds, as well as some of the organic substances, are sometimes deposited at a lower depth, leading to a greater or less degree of solidification of the mineral soil (hard pan, iron pan). These phenomena occur in varying degrees in forest soils where humus decomposition is bad. A cool, wet climate favours the process.

The course of humus formation is influenced by the nature of the soil. Soils poor in bases—especially lime—are always least favourable. It is also influenced by the nature of the crop, which determines the nature of the leaf fall, as well as by the ground vegetation. The spruce, among European trees, is especially prone to raw humus formation. The same is true of the pine, but in this case chiefly through the ground vegetation (heather, etc.), which often accompanies it. Silver fir and beech are also apt to produce raw humus on soils deficient in lime, which are too wet or too dry. The needles of the conifers are poor in mineral matter and appear to be less easily decomposed by the micro-organisms than the leaves of broad-leaved trees. The mixture of such leaves with the needle-litter seems to facilitate the decomposition, perhaps by improving the physical texture of the mass as well as its chemical nature.

Plant and Animal Life in the Soil.—The most important role *in the breaking down of the humus is played by the micro-organisms*, especially bacteria and fungi, in the forest soil. Only very few of these organisms have been isolated and very little is known of their life conditions. Their numbers are enormous; as many as 50 million fission fungi and innumerable filamentous fungi have been found in one gram of dry substance in the leaf litter (Ramann). The filamentous fungi generally predominate in dense, acid soils, and the total number of organisms is less. In open soils, with good humus decomposition, the numbers are much greater, especially those of the bacteria.

The importance of the course of decomposition of the organic matter in the soil provides an opportunity for the forester to influence soil fertility by operations which influence the life conditions of the micro-organisms which affect the decomposition. Light, heat and moisture are important features in those life conditions and are affected by the silvicultural technique employed in the forest. Existing conditions, if favourable, can be maintained by refraining from making drastic changes in the canopy (such as clear fellings) or in the composition of the litter (*e.g.* raising pure woods in place of mixed ones). On the other hand, where there is an accumulation of raw humus, exposure of the soil by opening the canopy, sometimes even large clearings, will often provide conditions which promote its rapid decomposition and nitrification. Every attack on the crop produces changes in the heat, light and moisture, and acts immediately on the biological conditions. The exact effect in a given soil is a matter for investigation. There is no doubt that the proper mixing of species and the planting of suitable shade-bearers under light-demanders have a beneficial effect on the formation of humus and the fertility of the soil.

Effect of Tree Roots on the Soil.—According to H. Burger, the roots of trees and the channels left by their decay play an important part in the aeration of the soil in the forest. Such channels are absent in arable and pasture soils and the air capacity of forest soils is found to be greater than that of soils in the open. These effects are more important in the heavier soils in which aeration tends to be deficient than in light sandy soils in which it is the water holding capacity which is small.

(3) Conditions in the Margins of Woods

The conditions in the edge of the forest, where it abuts on open ground, are modified through its exposure to the sun, wind and rain, and these effects penetrate to a greater or less distance into the forest acccording to the nature of the margin itself and more especially to the direction to which it is exposed.

The marginal trees in a wood which have been exposed during a large part of their lives, have generally green branches reaching down nearly to the ground, sturdy stems and well developed root systems, which not only make these trees windfirm, but enable them to act as a screen for the trees and soil further inside. Nevertheless, the increased access of light, heat, wind and rain produce modifications in the conditions just within the edge of the forest. These modifications extend further, however, and are more marked, when, through the felling of trees, a margin is created without those characteristics which are the result of development from early youth in exposed conditions.

The danger of exposing trees, previously protected by their neighbours, to the full force of the wind has long been recognised in forestry, and in order to avoid wind-fall and wind-break, it has been the practice to make fellings in adjoining areas follow each other in a direction contrary to that of the prevailing winds. In western Europe the strongest winds come as a rule from the west or south-west, but local topography may modify their direction in a given place.

Whilst the influence of the adjoining open ground penetrates into the border of the forest, the influence of the forest extends to a greater or less extent over the border of the open ground. On the side of a clearing in the forest, the shading by adjoining trees reduces the amount of sunshine and diffused light to a degree depending, not only on the height of the trees and the distance from them, but also on the aspect. The other effects of the forest canopy extend to a greater or less extent over the ground near it. There is therefore a strip both within and without the forest margin in which conditions show a transition from those of the forest to those of open ground.

Christopher Wagner investigated the climatic and soil conditions of different wood margins and laid stress on the favourable character of the northern margins of woods and the adjacent edge of cleared ground for young regeneration in European conditions. The direct rays of the sun are kept off the ground during the warmest part of the day, there is little exposure to wind during the growing season, as the north wind blows mainly during the winter. The result is that soil moisture conditions are better than those on other wood margins. The eastern edge of a wood receives less rain than the western and dry, cold winds during the spring are often experienced, whilst the morning sun, shining on frozen shoots, is apt to injure them. The southern margin receives the full force of the sun in the hottest part of the day and the soil is always dried out to a greater or less extent. The western margin receives most rain, but it is also exposed to the sun in the latter part of the day, when soil and

air have already been warmed up, and wind is also generally most troublesome on this exposure, so that evaporation is considerable. According to Wagner, therefore, who is supported by others, the eastern and north-eastern margins, created by the practice of successive fellings proceeding in a direction contrary to the prevailing wind, are not so favourable for regeneration as the northern or north-western margins. Whether this is true in a given case, and to what extent considerations of protection against wind break may be safely ignored in order to take advantage of the more favourable conditions for regeneration resulting from a different orientation of the felling front, are matters which the forester should take into consideration.

6. THE FORM OF TREES

No two trees, even of the same species, are exactly alike in form, and it is part of the task of the forester to guide the growth of the trees in his woods, so far as he can, towards the development of such forms as will give the most satisfactory material. Reference has been made in previous sections to the effect of some of the factors of the environment on the form of trees (see under Light and Wind) and it is proposed now to go into the matter of tree form more fully.

The great height reached by trees is the result of their exceptional energy of upward growth persisting for a long period of years, and this energy is possessed, in a special degree, by one of the features in their structure—the *stem*. Besides growing upwards, the tree also extends its branches outwards and develops a more or less wide-spreading *crown*, with a large number of leaves which are exposed to the light and to the atmosphere, from which they extract the carbon necessary for the tree's growth. In the soil, sustaining and anchoring the stem in its upright position, and taking in the moisture and soil nutrients, is a massive *root system*.

In the life economy of the tree the stem performs three functions. It raises and supports the crown high above the competition of other vegetation, provides a means of transport to and from the crown of various substances, and acts as a store-house for reserve materials not immediately required for growth. As the crown increases in size, owing to the constant production of new shoots, the demands on the stem for mechanical support, and conducting and storage capacity increase also. These demands are met by the stem growing in thickness.

The form of the tree depends on its inherent disposition and on the external environment. Every tree inherits from its parents certain qualities and potentialities which determine the

main lines of its development. According to modern ideas of genetics, it is not the actual form of the tree which is inherited, but rather the disposition to respond in certain ways to the external conditions. The so-called normal or typical form of the tree is the result of the working of a definite combination of external factors, any alteration of which will produce variations from the normal form. It is for this reason that no two trees are exactly alike, even if they have the same inherent disposition. There are always accidental differences in the environment which prevent identical development.

Though the external environment has such a powerful influence on the form of the tree, there are certain features in its structure which it appears powerless to alter. Some of these features have been used by botanists to distinguish different species, but it is now recognised that many of the so-called *true species* can be further sub-divided into sub-species, varieties and races. In modern forestry the importance of local races is becoming more and more recognised. Such races may differ from each other very little in the morphological features which interest the systematic botanist, but may differ greatly in their reactions to climatic and soil conditions, form and rate of growth, resistance to diseases, insects and adverse weather conditions, etc., which are of first importance to the forester.

Trees grown in the open develop the form characteristic of their species and display their inherent dispositions most clearly. They obtain light from all sides as well as from above and so are free to extend their crowns laterally as well as to grow upwards. In such circumstances, most broad-leaved trees develop a rounded and wide-spreading crown, with a short, thick stem, tapering rapidly from a broad base and breaking up into a number of branches. (*Plate* I, *facing p.* 65.) After early years the predominance of height growth over lateral development falls off rapidly in such trees. In many conifers, on the other hand, the tree is formed of a main stem covered with branches from near the ground to the top, and the stem is distinguished from the branches, not only by its direction, but by its greater thickness. The crown is conical or spire-like with a sharp top. In other cases, as in the Scots pine, the main stem in old trees is generally distinct for a considerable height and then breaks up into branches, the crown being more or less rounded or flattened at the top. The actual form of the crown of the tree depends on a number of factors, such as the character of the axis within the crown, the arrangement of the buds, the angle of branching, the lateral extension of the branches, the richness in the production of twigs, etc., all of which differ from species to species and even from race to race, but are more or less common to all members of the same species or race.

The form of the crown is also affected by interferences from outside. Wind in exposed places affects its shape by mechanical and physiological action and causes marked deviations from the typical. When trees are grown in close woods the growing space is restricted and the crown is confined to the upper part of the tree, provided the tree is in the upper canopy and can obtain light from above. The stem is then long and slender and tapers very little. (See: *Frontispiece.*) When the tree is completely overshaded it often tends to spread laterally. (See p. 27.) The crown of a tree may become one-sided or irregular owing to restrictions in its growing space.

Though the restriction of the development of the crown in close woods causes a diminution in the total growth of the individual tree, the *form* of the tree is greatly improved from an economic point of view, as long, clean, straight stems are the most desirable product. Since this is the case, some discussion of the way in which the tree stem is built up and the factors which affect its growth and form is not out of place here.

The stem is formed essentially out of a series of *annual shoots.* Each year the terminal bud, or more generally in broad-leaved trees, the topmost lateral bud, grows out into a shoot which attains its full length in one growing season and retains ever after the length then reached. The whole series of annual shoots increases in thickness each year, by the addition of a sheath of new wood on the outside of the previous wood, and the formation of new phloëm (living bark tissue) on the inside of the previous phloëm, through the activity of the *cambium,* a thin layer of living cells between the wood and the bark. When the stem is cut across, the successive additions to the wood can usually be seen as rings of tissue—the so-called *annual rings.*

No change in length of the stem can occur except by way of addition at the top and no change in thickness, except by way of addition to the outside of the original core of wood. Each annual shoot produces leaves and a certain number of buds, one or more of which may give rise to branches, which themselves grow in the same way. When grown in close woods the lower branches of the crown are overshaded by the upper ones of the same and neighbouring trees, die and ultimately fall off, leaving a clear bole of greater or less length, depending on the species, the age of the tree, the density of the crop and the various factors of the environment. When the stem has once broken up into a number of branches there is no longer any means of lengthening the clear bole, because nothing can raise the bases of these branches above their original height from the ground.

The base of every branch forms a *knot* in the timber of the stem. When a branch dies and breaks off close to the stem, the

wound is covered in the course of time by the outgrowth of wood and phloëm tissues from the cambium surrounding it. This process is called *Occlusion,* and when it is completed, the tissues added outside in later years show little or no trace of the former presence of the branch, so that in a large tree whose lower branches have long since disappeared, the outer part of the stem is free from knots. Knots in timber are always blemishes and the larger they are the longer they take to heal over and the more serious the depreciation in the value of the timber due to their presence.

As the wood of the stem increases in thickness by the addition of new wood on the outside, changes in shape can be produced by differences in the thickness of the accretions at different places. If a greater thickness of wood is added in the upper part of the stem than in the lower, the stem becomes less tapering; if more material is added in one diameter than in others, the stem becomes elliptical in section. Generally speaking, the stem of a tree grown in a close wood shows annual rings wide near the base, gradually diminishing for a certain distance, then increasing up to the base of the living crown and diminishing rapidly within the crown. It is possible to distinguish the so-called *root-swelling* near the base, passing fairly rapidly into the main part of the stem which tapers more gradually up to the top. Whilst this description applies in general to the clear stems of trees whose crowns are in the canopy of fairly close woods, the larger, over-dominant trees have more tapering stems, whilst partially suppressed ones have more cylindrical ones. In the latter case, the annual rings near the bottom may be very narrow, or even absent all together in certain years, though present in the upper part of the stem. In trees which have been given more room after having been growing in a close stand, not only is there generally an increase in the rate of growth in thickness, but the increase is greater near the bottom than near the top, so that the stem becomes more tapering.

A phenomenon of common occurrence is *excentric growth* of the stem. This is the result of the furthering of growth on one side as compared with the rest. The stem has an elliptical section, and it is found that, generally speaking, the longer axis of the ellipse, in all stems in a given site, lies in the same direction. This direction is that of the prevailing wind. Excentric growth in thickness of the branches is also quite common. A large horizontal branch of a conifer is often elliptical in section, with the long axis of the ellipse vertical, the lower side of the branch having the widest annual rings. In a conifer which exhibits excentric growth, it is the side of the stem away from the wind which shows the widest rings. This side of the stem is under pressure when the wind bends the tree over, just as the

lower side of the branch is under compression owing to its weight and that of its appendages bearing it down. In broad-leaved trees it is the side which comes under tension whose growth is promoted—in stems the windward side and in branches the upper side.

From the above description it is clear that the thickening of the stem is not purely automatic and uniform. It is controlled and directed by the living tree and various theories have been advanced as to the principle on which its distribution is based. The theory which appears to offer the most satisfactory explanation of many phenomena of diameter growth is one advanced by Metzger, which suggests that the distribution of increment in the stem is governed by the requirements of the tree for mechanical strength. The stem is subject to strains which cause variations in pressure and tension in various parts, and, according to the theory, these act as stimuli, which cause the cambium to become more or less active.

If a beam is fixed at one end and a force is applied at the other end at right angles to the beam the latter is most likely to break at the fixed end, because the force acts with the greatest leverage there. If material is to be economised a beam of adequate strength at the fixed end may be made to taper from that end to the other. If the beam is so shaped that it is equally able to resist the force in all parts, it is said to be a *Beam of Uniform Resistance*. According to Metzger (and other investigators have confirmed his observations), the clear stems of spruces, above the root swelling, very closely approach such beams in form, and the changes their shape undergoes during life in consequence of altered requirements are the same as those which must be carried out by such beams according to the laws of mechanics. According to these laws, a beam of uniform resistance is a cubical parboloid, in which the third power of the diameter D_x is proportional to the distance x between the place of measurement and the point of application of the force, *i.e.*, $\frac{D_x^3}{x} = C$; where C is a constant increasing with the magnitude of the force. When the cubes of the diameters of spruce stems were plotted against the heights at which they were measured, a straight line was obtained through the centre of gravity of the crown, which may be considered the point of application of the force, in this case, the wind. The presence of the root swelling, where the stem is over-strengthened according to the requirements of the theory, is connected with the transference of the strains from the vertical stem to horizontal roots.

The theory also accounts for the fact previously mentioned that when a tree is given more room the thickening of the stem is greater in the lower part than above. Greater isolation in-

volves greater exposure to the wind, and the increase in size of the crown which follows a freer stand gives the wind a greater hold. The laws of mechanics require a more rapid increase in diameter from above downwards to sustain the increased force and the expression $\frac{D_x^3}{x}$ becomes larger.

A horizontal beam made to sustain a weight at the free end would not be made of square section if economy of material was desired, but would be given an oblong section with the greater length of the oblong vertical. The circular section is required only when the force to be resisted may act in any direction. In the case of a tree, when the most frequent and strongest winds come from a certain quarter, the promotion of growth in the diameter in line with the mean direction of such winds is explained by the theory. As it is the strains set up by the bending of the stem that stimulate growth, growth will be greatest where the need for strengthening is greatest, and the stem will automatically adjust its form to the requirements brought into existence by the conditions.

Though the mechanical theory of stem thickening explains many of the phenomena, it does not account for all the facts. The measurements quoted by Metzger and others give considerable support to the theory in the case of older spruce stems, and also those of silver firs, larches and pines, which have for a long time been free from branches, but the shape of most stems is too irregular, owing to the inclusion of the bases of branches, which affect, not only the shape, but also the strength of the timber. The stems of broad-leaved trees do not conform to the requirements of a beam of uniform resistance, so that there are other factors of greater or less importance which influence the shapes of stems, even if purely mechanical requirements predominate in certain old conifers.

There are two factors which appear to influence the direction and shape of tree stems, whose effects become evident in certain circumstances, *viz.*: *Gravity* and *Light*. The main axis of a tree is *negatively geotropic;* it grows straight upwards against the force of gravity, unless something occurs to bend it out of the vertical. It is also *positively heliotropic, i.e.* it tends to grow towards the light. In normal circumstances the two factors, light and gravity, act in unison. The relative importance of the two factors appears to differ in different trees. In most conifers sensitiveness to gravity preponderates to such an extent as to mask any effect of the light stimulus. Even when illuminated from one side, as at the edge of a wood or on a steep slope, the stems of spruces grow vertically upwards. When, however, an opening is made in a wood of broad-leaved trees, the trees on the margin bend into the gap, to take advantage of the oblique

light which reaches them. According to Arnold Engler, this is not a mere mechanical bending under the increased weight of the crown on the better lighted side, but a true light stimulus action.

When a young conifer is tilted out of the vertical by the movement of the soil or partial uprooting by the wind, the stem gradually curves back until the upper part becomes upright. On the lower side of the tilted stem increase in thickness is greater than on the upper side, and, moreover, is associated with the formation of so-called *pressure wood,* or *red wood*, which differs from the normal wood by being redder in colour and more resistant to pressure. Whether this increased growth and the production of pressure wood are due to gravity or to a pressure stimulus is not quite clear, but the weight of evidence is in favour of a gravity stimulus.

A similar phenomenon is exhibited when the leading shoot of a conifer is broken off. Then the nearest lateral branch, whose normal position is at an angle with the vertical, bends up gradually until it places itself as nearly as possible in a line with the vertical stem, and this erection is also associated with the furthering of growth and the production of pressure wood on the outer and lower side. All the branches near the lost leader are influenced in the same way, the nearest the most strongly. When two or more branches are equally near and about equally developed, they may all turn upwards and grow on with the vigour characteristic of the leading shoot so that the tree becomes forked or many leadered. Erection of the nearest lateral branch to replace a lost leader also takes place in broad-leaved trees.

The straight vertical form of the stems of spruces, silver firs, etc., appears to be due to their powerful geotropism. Response to the gravity stimulus is not so pronounced in broad-leaved trees and does not persist so strongly in later years in pines. The shapes of individual stems may vary from the typical by reason of the different hereditary properties of the tree, its sensitiveness to various stimuli and the conditions in which it grows. Different species and races of trees display characteristic variations from the straight, upright form of stem, and the range of variation is wider in broad-leaved trees than in conifers.

The erection of a lateral branch into the position of leader when the original leader is destroyed, though its mechanism may appear similar to that employed to erect a displaced stem, introduces a new factor into the problem of tree development. Before the leader was destroyed, the branch showed no disposition to erect itself, but had its own direction in space. While it seems fairly simple to explain the erect position of the stem by assuming its sensitiveness to gravity, it is not so easy to account for the direction and position of lateral branches by a similar assump-

tion. That the lateral branches each have a definite direction and strive to correct any displacement they may have suffered has been proved over and over again by experiment. The latest work on the subject by Hartmann seems to demonstrate that neither gravity nor pressure and tension can account for the phenomena observed, but that the posture of a branch depends on the position, size and direction of all the other branches. It is an example of what has been called *Correlation,* by which is meant the interdependence of all the organs of the plant. The length and direction of every twig is influenced by the presence of other twigs.

The principle of economy of material and energy seems to govern the tree's development. Many buds, for example, fail to grow into shoots in the year after their formation, but remain dormant. They are chiefly those in the lower parts of shoots, the twigs from which would be badly lighted, and so inefficient. If, however, the shoot beyond the bud is injured or removed, the bud will waken into life and provide foliage to replace the loss. If a branch or twig becomes overshaded and cannot nourish itself and provide a contribution to the stem that bears it, it dies, and the water and soil nutrients it would have used fall to the benefit of better lighted neighbours. If the downward development of the main root is checked by shallowness of the soil, height growth is also checked. Root and crown develop in balanced relationship to one another and with the environment. If the environment alters the balance alters accordingly. Increased isolation of the tree, for example, permits of greater crown development, but this is carried out *pari passu* with the development of stem and roots. Adjustment of the form of the tree to new conditions is carried out by growth processes and is necessarily slow. If the alteration of conditions is too sudden and drastic the tree may be injured. When, for example, trees, hitherto sheltered by others are suddenly exposed to the wind, they are likely to be broken or thrown by a storm, but if they are exposed gradually by successive stages, and have time to adjust themselves to the changing conditions, they may become windfirm.

The tree is an organism in a constant state of growth and development, adjusting itself to its environment through its sensitiveness to various stimuli, to which its inherent properties enable it to respond in suitable ways. Gravity, light, pressure and tension are some of these stimuli, but there are doubtless others which have not yet been identified. It is the task of science to trace out as far as possible the nature of the responses of the living part of the tree to the outer world. How this sensitiveness of the protoplasm to such influences arose, and how it has become integrated into what might be called the spirit of a tree, is unknown and possibly unknowable.

CHAPTER III

THE PRACTICE OF SILVICULTURE

1. DEFINITION

Silviculture is the branch of Forestry which deals with the cultivation of the forest, with the object of satisfying man's requirements for its products in a systematic manner. The products of forests are; firstly *wood*, for fuel, building and innumerable industrial purposes, and secondly a whole number of other materials obtained from the trees or from other plants associated with them, such as: bark, resin, gums, rubber, fruits, grass, litter, moss, herbs, fungi, etc., which are usually classed together as *Minor Forest Products*, whilst wood is spoken of as the *Major Forest Product*. In the forests of Europe, where systematic forestry first began, wood has long been actually the major forest product in importance and value, but in some countries, especially in the tropics, the value of the so-called minor forest products exceeds that of the wood. In such countries, however, silviculture is practically unknown, so that silviculture is concerned primarily with the production of wood, but it may take account, in certain cases, of the production and harvesting of other materials, such as bark for tanning, resins, etc.

2. THE RELATION OF SILVICULTURE TO FOREST MANAGEMENT

Silviculture is undertaken mainly for economic purposes. It is a business enterprise and its methods must be governed by economic considerations. The characteristics of an efficient productive industry are regular and continuous economical production. An efficient factory is designed for the continuous production of a certain kind of article, the costs of supervision and operation bear a suitable relation to the value of the product, the plant and machinery are run continuously and at full capacity with a minimum waste of power, wear and tear are reduced to a minimum and repairs and replacements are made where necessary out of profits. The condition of a properly managed forest may well be compared with such a factory. It is designed and worked

for the continuous production of timber of certain species and assortments, the costs of supervision and labour are kept in economic relation to the income, the productive power of nature, operating through the soil, climate and trees is utilised to the full, and where any injury is done to the soil or growing stock, their condition and efficiency is restored even at the expense of a reduction of profits.

In spite of this superficial resemblance between silviculture and manufacturing industry, the difference between them is profound. Not only is the knowledge which the factory manager possesses of the nature and working of his plant more complete than that of the silviculturist, but there is a fundamental difference in the nature of the plant in the two cases. Even the factory manager cannot get the best out of his factory unless he gets the co-operation of his workpeople. Here he comes in contact with problems of psychology and hygiene, and differences in capacity and disposition of individuals, all of whom have their own objects in life, to which their activities in the factory are only incidental. How much more complicated is the problem of the forester, whose very machinery is alive and working for its own ends?

One characteristic of silviculture is the length of time which it takes for the fruits of any expenditure to be reaped. This affects the economic relationships of costs and receipts, for reasons which will be discussed under Forest Economics. It greatly reduces the amount which may be spent on silvicultural operations and may considerably modify the aims of silviculture. Secondly, the time required to grow trees to useful dimensions, makes it necessary, in order to obtain the great economic advantage of regular and continuous output, that the forest should be organised so as to contain woods of such ages and sizes as to form a regular succession, from which the required annual or periodic supply of materials for the market may be obtained. To ensure that production should go on indefinitely, it is necessary that the trees removed should be replaced by a new crop without delay, that the fertility of the soil should not be reduced, and finally, that the felling of any wood at maturity should not cause damage to other woods in the neighbourhood by exposing them unduly to adverse influences.

A properly managed forest is therefore an organised collection of *woods,* each of which is treated in such a way as to produce the prescribed kinds of material, which can be extracted without reducing the productive power of the soil and replaced by a new crop. In the sense that the word is used here, a *wood* is a silvicultural unit in the structure of the forest. The building up of the woods of different kinds and in different stages of development into an organised whole is the function of *Forest*

Oak grown in open forest. Age about 400 years. Height to lowest branch about 10 feet.
(New Forest, England.)

See: p. 56.

Management which it endeavours to carry out by prescribing the nature, time and place of the various silvicultural operations.

Silviculture is not an exact science but an art. From past experience and study of the ecological conditions and the responses of trees to them, it has been possible to devise methods of treating woods which guide their growth and promote their regeneration, but the application of a method in a given case, owing to the infinitely varied and varying conditions, may lead to results more or less different from those aimed at. Nevertheless, the laying down of certain rules of procedure for the guidance of the operator is all to the good, as it preserves continuity of aim and method and prevents uncontrolled experimentation by inexperienced foresters. The validity of these rules must depend on the amount of silvicultural experience and knowledge of the local conditions on which they are based. They should not be regarded as unalterable, but, at the same time, departures from them should be justified only by experience of their working and increased knowledge of the conditions of the forest and locality.

Such rules are incorporated in the Working Plan, which is drawn up after due consideration of silvicultural and economic conditions; it is carried out by the silviculturist, but if it is found that as a result anything is not satisfactory from a silvicultural point of view, it is his duty to call attention to it and suggest alterations. Similarly, it is the duty of the management to take similar action if there is anything amiss from the economic standpoint. The modern tendency is for the silviculturist to be given freedom to exercise his discretion within certain limits, but if he desires to go outside those limits, he must make out a case and get the consent of the management. Moreover, provision is made for the revision of the working plan at comparatively short intervals so that changes in the procedure, which suggest themselves as the result of experience, may be incorporated.

3. THE WOOD OR STAND

(a) **The Size of Woods.**—A wood or stand is an area of land carrying a crop of trees of sufficiently uniform character to be subjected to one method of treatment. It forms a silvicultural unit in the forest. In economic forestry, it must be sufficiently large to justify separate treatment, but the minimum actual area which will satisfy this condition will differ according to circumstances, *e.g.* the value of the products, intensity of management, etc. The size of a wood may be anything from the smallest area which will justify individual treatment up to almost any limit, but in practice, woods of great size involve difficulties in supervision and uniform treatment and are exposed to excessive

dangers from storms, fire, etc., so that very large woods are generally divided up by roads, rides, etc. The smaller a wood is, the more are the conditions within it influenced by neighbouring woods and open ground. The influence of the surroundings may be of various kinds; letting in or excluding light, blowing in of leaf litter, scattering of seeds from adjoining woods, shelter from wind, etc. These various effects extend to different distances; but, on the average, may be said to operate within the length of a tree, say 60-90 feet. A *small* wood may therefore be defined as one in which the influence of the surroundings is shown appreciably over most of its area, whilst a *large* wood is one in which conditions are governed mainly by its own crop and the influence of the surroundings is confined to unimportant margins. In this matter the *shape* of the wood also has an influence. A long narrow belt of trees will have the ecological characteristics of a small wood, in spite of its considerable area.

(b) The Composition of Woods.—When a wood consists of a single species or when one species predominates to such an extent as to determine exclusively its condition and treatment, it is said to be a *Pure Wood.* When two or more species occur in significant proportions, the wood is a *Mixed Wood.* The proportion of the different species in a mixture may be expressed in various ways, *e.g.* in terms of the stem area, volume of timber, number of trees, or ground occupied by the crowns. Each of these methods of assessment has advantages and disadvantages from an economic or silvicultural point of view. For example, an underwood may possibly provide an insignificant fraction of the volume or stem area; but, nevertheless, have great ecological and silvicultural importance.

The character of a mixed wood is determined, not only by the nature of the species and their proportions, but also by the way in which they are mixed. Mixture may be by single trees, by small or larger groups, by lines, by strips, etc. If the areas occupied by a single species are large enough to determine their own ecological conditions and call for separate treatment, we are no longer dealing with a mixed wood, but with a collection of pure woods. The characteristics of mixed woods are most fully developed when the mixture is an intimate one of small units, such as single trees, lines or small groups. Such woods are, however, the most difficult to manage.

As woods get older and the trees become bigger, many individuals disappear and this may lead to changes in the composition of the wood, if one or more species are eliminated, either naturally or through the method of treatment. Moreover, the manner of mixing may be altered owing to the disappearance of individuals, so that mixture by small groups may pass into

mixture by single trees. New species may be introduced in the course of the wood's life. Mixtures may therefore be permanent or temporary, even-aged or uneven-aged.

(c) The Constitution of Woods.—By the constitution of woods is meant their structure in a vertical direction—the distribution in height of the crowns of the trees. If the crowns of the trees are all approximately at the same level so that they form a horizontal layer, below which is an empty stem space, the wood is said to be *even-aged,* or better, *one-storied.* This condition of affairs does not always mean that the trees are all of the same age, because the rate of height growth falls off as trees become older, and younger trees, if they have access to light, catch up with their elders. A small difference in age of the trees ceases to be significant in later years.

When, below the main layer of crowns, there is a distinct second layer in the middle or lower part of the stem space, the wood is said to be *two-aged* or *two-storied.* Again the terms are not synonymous, because in mixed woods it is quite possible for one species, especially a shade bearer, to lag behind another in height growth and produce, at any rate for a time, the two-storied condition.

When more than two layers of crowns are present in a wood, it is said to be *uneven-aged* or *many-storied.* It is seldom that more than two layers of crowns occur actually under one another. When the stem space appears to be filled with foliage, it is generally because a number of height classes occur side by side, so that the canopy rises and falls.

In this book the terms *even-aged* and *uneven-aged* will be used in the sense of *even-heighted* and *uneven-heighted* without being necessarily associated with actual age. The terms *regular* and *irregular* might be more suitable, but the latter is more often used to describe a wood which is not only uneven-heighted, but also has the height classes mixed by small groups or single trees irregularly distributed, as distinct from one in which the height classes are arranged in some sort of order.

(d) The Relative Merits of different Kinds of Woods—Most natural woods are mixed, but pure woods are by no means unknown in the natural forest. Generally speaking, they occur where the conditions suit only one species. For example, on certain poor sandy soils in Europe and America, species of pine occur in pure woods. Again, in extreme climatic conditions, as in the far north or at high elevations, the number of species that can stand them is small, and the spruce forms pure woods, though of poor quality and productive capacity. Certain species also, in conditions which suit them very well, are so vigorous and aggressive that they crowd out others and form pure woods.

Species are more prone to form pure woods in those parts of their habitat in which conditions are at the optimum and as these are departed from more and more individuals of other species appear and hold their own in the woods.

Even-aged woods also occur in nature where fire or wind storm has destroyed the previous crop. Owing to the slowing down of height growth, woods actually of uneven age, as time goes on, become more or less one-storied.

The advantages of *large woods* are ease of supervision and the concentration of silvicultural operations, fellings and sales. These advantages are economic. The disadvantages of such woods are the greater seriousness of the dangers to which they are exposed. Fire, storms, insects and fungi, finding conditions favourable for their attacks over large areas, may do serious damage and acquire a momentum which makes them a menace to the whole forest.

The advantage of *small woods* from a silvicultural point of view is the greater freedom of treatment. The presence in the forest of a number of different places in which felling, regeneration, etc., may be carried out, makes for regularity of yield, as the mature timber is not all concentrated in a few large woods where conditions may not be favourable for exploitation and regeneration at the prescribed time. On the other hand, small woods mean a greater proportion of marginal trees, which are apt to be poor in form, the overshading of young growth by older neighbouring stands, etc. Where, for reasons of protection, it is necessary to fence young woods, the cost of fencing per unit area protected, increases with decreasing size of the woods. Nevertheless, by proper arrangement of the woods on the ground, suitable orientation of the felling front, use of marginal conditions for encouraging regeneration, etc., small woods may be built up into a highly efficient forest, though one which requires intensive working and skilled management and a very complete system of roads and rides.

Pure woods are easier to manage than mixed woods; but, on the other hand, are more exposed to certain dangers. This does not, however, apply to all dangers and is only true if the mixture is a suitable one. It is obvious that the safety of a wood of a storm-resisting species is not increased but diminished by the introduction of one which is easily wind thrown. The spread of insect plagues is hindered by mixing of the species. In addition to greater freedom from dangers, there may be a more complete utilisation of the soil nutrients, through differences in the demands of the constituent species and differences in their depth of rooting. In general also, the decomposition of the humus is more favourable in mixed woods than in pure ones.

Everything depends, however, on the proper choice of species for mixing together. Generally speaking, the most valuable forms of mixture are those of shade bearers with light demanders. Most of the valuable timber trees are light demanders (*e.g.* oak, chestnut, ash, larch) and when grown in pure woods to an advanced age, they are unable to maintain the fertility of the soil, the crops open up, the trees themselves become branchy and poor in shape, the ground becomes overrun with weeds and regeneration is difficult or impossible without considerable artificial aid. By mixing a suitable shade bearer with the light demander these drawbacks are avoided. Mixtures of shade-bearers among themselves are generally less advantageous, whilst the least valuable are mixtures of light demanders.

Mixed woods are, however, more difficult to treat owing to the different rates of growth of species and their different shade-bearing capacity. Light demanders cannot stand the shade of shade bearers and must always be given freedom for the adequate development of their crowns. Where there is a tendency for the shade-bearing species to get ahead, constant vigilance and timely intervention by the forester are required. A short period of neglect or inadequate measures will cause irreparable damage to the wood. These difficulties may be minimised by giving the sensitive, light-demanding species a few years' start.

Uneven-aged woods are more secure against certain dangers than even-aged woods. Wind storm, snow break and fire are less liable to do extensive damage in certain kinds of uneven-aged woods. It is also claimed by some that they utilise the light more fully and that volume production is greater. The idea that by growing one storey of trees above another, an increased volume production necessarily follows is open to question. Besides the powerful shading effect of the overwood on the underwood, their mutual root-competition must not be lost sight of. Much depends on the species, quality of the soil, nature of the ground vegetation, etc., and it is unsafe to generalise. One undoubted advantage of irregular, many-storied, woods is the greater stillness of the air in their interior.

Owing to the parallelism in working of the various forms of woods, the disadvantages of one may be set off against the advantages of another. Thus the risks of large woods are diminished if they consist of a suitable mixture, and those of pure woods if they are small or uneven-aged. The obvious economic advantages of simplicity of working and management led in the past to the creation of large, even-aged, pure woods of conifers in certain parts of Europe, where mixed woods were formerly present. The disadvantages which became evident later, in soil deterioration, insect plagues and fire and storm damage, have

caused a revulsion in favour of small, mixed and uneven-aged woods.

Many species are quite able to grow in pure woods without deterioration of the soil and to produce good quality timber under favourable conditions. If the drawbacks from the point of view of protection are minimised by avoiding large woods of even age, the gain in simplicity of treatment and management makes such a method of growing them most profitable. Nevertheless, it is undoubtedly sounder silviculture, where naturally mixed woods exist, to maintain them as such rather than to convert them into pure woods and run the risks which this practice is apt to involve.

4. REGENERATION AND AFFORESTATION

By *Regeneration* is meant the process of replacing the crop of trees in a wood by a new one. In nature regeneration is normally a slow process, but it is sufficient because the disappearance of old trees is also slow. When a catastrophe happens, such as a fire or wind storm which destroys the forest over a considerable area, very often the species which spring up naturally are different from those which formed the dominant members of the previous crop. The new type of forest is, however, transitory and, in the course of time, gives way to the type in equilibrium with the local conditions. In the absence of such a catastrophe, however, regeneration proceeds chiefly by the springing up of young growth in small gaps made by the death and fall of individual trees. In forests worked for timber production, the removal of trees is much more rapid than that due to natural processes. It is therefore necessary to devise means of bringing about regeneration without unduly restricting the exploitation of the forest, and this is one of the most important problems that the forester has to solve. In addition to providing for the regeneration of woods, the forester may be called upon to establish a crop of trees on land which was previously not under forest. This process is called *Afforestation*.

(a) Natural and Artificial Regeneration. — Regeneration is said to be *natural* when the young growth arises from seeds shed naturally on the ground by mother trees or when it is formed of shoots thrown out by parts of the old trees (stump, stem, branches, roots). It is termed *artificial* when seeds are sown or young trees planted by man.

(b) The Choice of the Method of Regeneration. — In some circumstances the forester has no choice but has to adopt artificial regeneration, *e.g.* when a new species is to be introduced, when, in consequence of some catastrophe (windfall, snow-

break, fire) woods not yet in the seed-bearing stage have to be regenerated, or if seed is not produced in the woods in adequate quantities. Afforestation is, of course, an artificial process.

In other cases, there is a choice of methods, but it is often a difficult one. The relative merits of natural and artificial regeneration can be appreciated only when the nature of the two methods and their technique is understood.

I. NATURAL REGENERATION

Natural Regeneration may be (1) by seed, (2) by coppice shoots, root suckers, etc. The latter methods are best considered when dealing with the Silvicultural Systems with which they are associated: Coppice, Coppice with Standards, Pollarding, etc. Regeneration by seed is much the more important and widespread.

Natural Regeneration by Seed

There are two main methods of bringing about natural regeneration by seed, viz.: (1) the area is cleared of trees and seed from trees on adjoining areas is relied upon, and (2) the seed is derived from trees standing on the area to be regenerated.

The first method is not largely practised. At best it can be successful only on rather narrow strips, which in practice should not much exceed in breadth the height of the trees in the neighbouring stand. The method is suitable only for hardy, light demanding species with easily scattered seed and for soil not excessively prone to weed growth. Cultivation of the soil is generally necessary. The method is practised with some success with Scots and other pines where conditions for regeneration are very favourable. Generally the stumps of the old crop are grubbed up, which ensures thorough cultivation of the soil. In other cases, the soil is cultivated artificially, generally in strips. The method is cheap and has the additional advantage that there is no damage done to young plants by the felling and drawing out of shelter trees, but the conditions under which it can be carried out successfully are limited, and in most cases it has to be supplemented by artificial regeneration to complete the crop.

The most important method of natural regeneration by seed is that in which the parent trees stand on the area to be regenerated. The method is generally called *Natural Regeneration under a Shelterwood,* because the trees of the old crop, besides providing seed, also provide shelter to the young plants. (*Plate* II A *facing p.* 96.)

In order to bring about natural regeneration, there are certain essential conditions which must be provided:

(1) The parent trees must bear a sufficient quantity of good seed,

(2) The soil must be in a condition suitable for the reception of the seed and the growth of the young seedlings,

(3) Sufficient shelter must be given to the young crop to protect it from the dangers to which it is exposed,

(4) Sufficient light must be given to permit of the healthy growth of the young plants.

Provided regeneration is undertaken within the limits of age in which the species in question is capable of bearing good seed, the first two conditions can, in ordinary circumstances, be achieved simultaneously. For the production of good and plentiful seed, the trees should have well developed crowns, exposed on all sides to the rays of the sun. Under a properly executed system of thinnings, such a condition can be brought about by a gradual increase in the severity of the thinnings up to the time when regeneration is to take place. The more open condition of the canopy will, at the same time, by letting more light and heat reach the forest floor, have promoted the decay of the thick masses of humus, without allowing the growth of troublesome light-demanding weeds. The attainment of a suitable soil condition is often proclaimed by the appearance of a thin population of shade-bearing weeds.

When the thinnings have not been adequate and, in consequence the wood is very dense and the crowns of the trees are narrow and badly developed, the process of regeneration is preceded by a *Preparatory Felling,* by which it is sought to bring about the desired conditions. Since the building up of better crowns only proceeds slowly at an advanced age and a sudden, sharp opening of the crop is liable to be followed by undesirable effects on the soil and danger to the remaining trees from the wind, the results of a preparatory felling are not so good as those of a properly regulated system of thinning. Nowadays the practice of heavier thinning in the latter years of the life of a wood is gaining ground and the preparatory felling is receding in importance. The newer system allows greater freedom to the forester, as all his mature woods are in a condition to be regenerated at any time.

The actual beginning of the regeneration is made with the *Seed Felling* or *Seeding Felling.* The object of this is so far to open up the canopy that the young plants from the seeds which have fallen will have sufficient light to grow for a few years, but at the same time, have sufficient shelter from frost and drought. In order to secure the success of the regeneration, the seed felling

is generally carried out in a year in which a good supply of seed is seen on the trees. This is not so important in the case of species which bear good crops of seed at short intervals, as with species (*e.g.* beech) in which good seed years occur more seldom. The felling and removal of the trees should be done in early winter so as to be finished before germination begins. At the time of the seed felling, the ground should be cleared of bushes and other weed growth, as well as any *advance growth* which it is not intended should form part of the new crop.

It is impossible to give general rules as to the amount of opening of the wood which should be done by the seed felling. In general, however, it is better to err on the side of caution and to keep the shelterwood rather dark, because young plants can generally stand a good deal of shade for the first year or two, whilst, if the expected regeneration does not take place, the undue exposure of the soil after a heavy cut, may lead to its deterioration and the overrunning of the ground by weeds.

After the young growth has made its appearance, the removal of the shelterwood is carried out in stages, as the young plants require more light and can do with less shelter. The number of stages in the process and the period over which it lasts, will vary with the species and the climatic conditions. Besides the requirements of the young plants for light and shelter, the damage which may be done to them by the felling and extraction of the old trees has to be taken into account. The damage is the greater, the older and larger the young plants. Species differ in their power of resisting and healing such injuries. Precautions should be taken to minimise the damage, *e.g.*, felling the largest trees in the early stages, felling trees into blanks and away from young growth, lopping and topping large trees before felling, dragging out over prescribed routes, and, if possible, over deep snow, etc. The period of retention of the overwood will be *short* with hardy, light-demanding species, with species which are brittle and easily injured and poor at healing injuries, and with species whose value increases very little with the increased size of large trees. It will be *longer* with sensitive shade-bearers, with such as heal their injuries easily, with those which increase rapidly in value with increasing size and do not suffer damage by isolation (epicormic branch formation, bark scorch, windthrow, etc.). The fellings in the shelterwood which remove parts of the standing crops are called *Secondary Fellings*. They are followed by the *Final Felling* by which the last of the old crop is removed. The time between the Seed Felling and the Final Felling is called the *Regeneration Period*.

The carrying out of the various regeneration fellings may vary greatly in detail. If the aim is to get uniform regeneration

over the whole wood or a large section of it at the same time, the cuts are made so as to get as evenly distributed a shelterwood as possible. This system is called the *Compartment* or *Uniform System* and, if successful, results in the production of an even-aged wood. Other systems aim at producing regeneration in small areas simultaneously and successively, so as to produce woods of a number of age classes, in groups, strips or a combination of both. Regeneration in a given group or strip may be brought about in a comparatively short time (Special Regeneration Period), but that of the wood as a whole occupies a greater number of years (General Regeneration Period). The number of systems of this class is considerable, owing to variations in the size and shape of the units (small or large groups, narrow or wide strips, etc.) and their arrangement (*i.e.* whether the regeneration moves in a definite direction through the wood or is spread more or less irregularly over it). In some systems the range of age classes may be comparatively short, in others long. In the so-called *Selection System* a complete series of age classes from seedlings to mature trees is maintained. Some further account is given of various *Silvicultural Systems* later in this book.

The brief outline of the systems of natural regeneration given above includes the methods which can, in general, be adopted only where forestry is *intensive*. That is to say, they are suitable where skilled management, close and regular supervision, adequate labour and a suitable system of transport routes, etc., are provided and are justified by the value of the products. These systems have been developed in European countries where systematic forestry has been practised for a long time. Their application to other countries and other conditions is subject to considerable limitations, but the principles on which they are based apply to forests everywhere and the forester should be familiar with them so that such measures as he can apply to the forest under his control shall be properly directed.

In the shelterwood systems the successive cuts, removing only a part of the marketable timber on a given area have to be made, so that the operations are scattered, and moreover are hindered by the consideration which has to be given to the safety of the young growth. Only where there is a good and ready market for material of all sizes will it be economically possible to carry out in detail all the measures which aim at making regeneration as sure as possible.

In forests in remote districts and undeveloped countries, where only the best timber is marketable and it is necessary to harvest this as cheaply and completely as possible, the problem of natural regeneration is much more difficult. It is just in such

forests, however, that it is most important, because artificial regeneration is even more closely associated with intensive working than natural regeneration. Clear-felling, or, at any rate, the felling of all the marketable stems, is the most economical system of exploitation, but is generally the most unfavourable for natural regeneration. In certain cases, regeneration does follow a clear felling, as where there are stores of seed in the surface litter which have retained their germinating capacity or where adequate quantities are afforded by the trees that are felled. Sometimes a few seed trees may be left distributed over the area, which, though not sufficiently numerous to form a shelterwood, supplement the store of seed already present and provide a new crop if the original one is destroyed by fire.

The large quantity of slash, *i.e.*, rubbish consisting of branches, twigs, faulty logs, etc., left on the ground after exploitation, in many cases, not only impedes regeneration, but forms a serious fire hazard. It should be piled and burnt, or burnt broadcast, before the young crop springs up. The effects of this preliminary burning may be beneficial, but fires occurring subsequently, which destroy the young crop are disastrous. The control of the burning of slash, cutting of weed growth, insistance on the retention of a number of seed trees, are some of the methods which may be employed to encourage regeneration in cases of wholesale exploitation. The effects of fire on regeneration should be studied, because it differs widely in different cases and with different species. Sometimes fire leads to regeneration quite different from that which would occur if no burning took place. In certain forests in India protection from fire has been found to encourage the regeneration of comparatively worthless species at the expense of the more valuable ones (*e.g.* teak and sal). In other cases, it is valuable species which are discouraged or destroyed by fire.

II. THE ARTIFICIAL FORMATION OF WOODS

Under this heading are included both Artificial Regeneration and Afforestation. The conditions in which artificial regeneration is carried out differ to a greater or less extent from those present in afforestation. On the whole regeneration is easier than afforestation, but each has its own problems, though the technique of sowing, planting, etc., is similar. In artificial regeneration the forester may have the opportunity of using the old crop as a shelterwood, if he so desires, in the same way as in natural regeneration. Artificial regeneration is, in fact, often practised under the shelterwood systems, as a supplement to natural regeneration and even, in some cases, as the main method. It is necessary when new species are to be introduced

and is very useful in increasing the proportion of certain species in mixed woods. It is also employed in ***under-planting, i.e.*** the introduction of a second crop under the original one. In the main, however, artificial regeneration is associated with clear felling, so that so far as exposure to the weather is concerned, the conditions are the same as in afforestation. It is in the nature and condition of the soil that the main difference lies. In artificial regeneration the soil is, or should be, a forest soil, with a good supply of humus, which in favourable circumstances, decomposes rapidly and provides the new crop with an ample supply of nutrients and good moisture conditions. At first the ground is generally more or less free from weed growth so that, if regeneration is effected without delay, there is little trouble from this cause, though, later on, owing to the fertility of the soil, a rapid development of ground vegetation may take place, which necessitates weeding and cleaning operations. On the other hand, the ***slash*** left on the ground after felling must be got rid of by burning or removal, and the stumps of the old trees interfere with cultivation. Moreover, certain injurious insects find breeding places in the stumps, roots and slash, and are apt to multiply so that special measures of protection may have to be adopted.

In afforestation, the ground is generally completely occupied by some form of vegetation which may compete with the young trees and the soil conditions are apt to differ considerably from those of forest soil.

The artificial formation of woods may be carried out in several ways which may be classified as follows:—

1. by direct sowing of seeds
    - (a) over the whole area
    - (b) in strips
    - (c) in patches
2. by planting
    - (a) of seedling plants
        - (1) with bare roots
        - (2) with balls of soil
        - (3) with containers
    - (b) of cuttings, layers or root suckers.

(1) Formation of Woods by Direct Sowing

For the success of the sowing and the subsequent development of the crop, the seed must be of good quality and of the right kind. Whilst methods exist for testing its germinating capacity, it is not always easy to determine its origin, and this is very important. Seed may be obtained locally from trees which have shown themselves by their growth and form to be suited to the locality, but it is sometimes necessary to obtain it from a

distance. It is not sufficient that such seed should be of the right species. It should also be of a suitable local race or variety. More and more attention is being paid nowadays to the origin of tree seeds and the suitability of various strains for different districts. (*See:* p. 56.)

It is almost always necessary to cultivate the soil. This may be done all over the area by ploughing and harrowing. Owing to the expense of repeated harrowings and hand cultivation, over the whole area, it is seldom possible to get a fine tilth. The more usual practice is to give a more thorough cultivation to parts of the area—strips or patches—leaving the intervening spaces uncultivated. Strips are cultivated where conditions permit of the employment of horse- or power-drawn implements, whilst when the presence of roots, rocks, etc., prevents this, and hand cultivation is necessary, it is generally confined to patches. The seedbed should be as fine as possible, free from stones and roots and consist of fine, uniform, small-crumbed soil. Fragments of surface humus, bark, etc., should be removed and the mineral soil exposed. This has generally to be thoroughly opened up by cultivation, but too loose a condition should be avoided owing to the danger of drying out of the surface. The soil should, therefore, be allowed to settle after stirring or be rolled before the seed is sown.

The seed may be sown broadcast, *i.e.* distributed thinly as evenly as possible over the whole area or the cultivated strips or patches. This gives the individual seedling a fair amount of room. On the other hand, sowing may be in *drills, i.e.* narrow lines or rows, in which the seeds are sown more thickly, so that the young plants soon begin to compete with each other. The advantages of the latter method are that it requires less seed and facilitates weeding by hand or by horse-drawn or mechanical implements. After sowing the seed should be covered to a suitable depth. The smaller the seeds, the thinner the covering should be as a rule.

(2) Formation of Woods by Planting

The common practice is to use plants raised from seed sown either artificially in a *Forest Nursery* or naturally in the forest. The cases in which cuttings, layers or root-suckers are employed are rarer in ordinary forestry.

(a) **Planting of Seedling Plants.** — Whatever may be the origin of the plants, they have to be taken up from their original position and inserted in the soil of the planting area. This process is apt to injure the roots, if they are separated from the soil in which they are growing, and the plant has to develop a new set of ab·orbing rootlets and establish contact with the soil in its

new position before it can take in its normal supplies of water and nutrients. This takes a certain amount of time, during which the plant is particularly susceptible to injury by drought and wind. It is therefore the main concern of the forester in carrying out planting operations, to minimise the injury done to the roots.

The smaller the root system of a plant, the easier it is to dig it up without losing much of it, but small plants find difficulty in holding their own in competition with weed growth and in sustaining the attacks of injurious insects and animals to which they may be exposed when they are planted out. It is, therefore, advisable to use plants which are not too small. If, in order to obtain a larger plant, a seedling is allowed to grow undisturbed for several years, it forms a deep, wide-spreading root system, which it is difficult or impossible to dig up without serious loss. If the seedling is lifted when it is still small, however, little injury is done to the main roots, though the feeding rootlets are mostly destroyed. If it is replanted, as a rule a larger number of new roots are produced and the root system becomes richly branched, forming a compact mass which can be handled easily and is capable of sustaining the plant even if some of the new, wide-spreading roots are lost. By treating seedlings in this way in the nursery where they can be given good soil conditions and can be looked after, plants of adequate size can be produced in which the balance between root and shoot system after planting is much better than in the seedlings of the same size which have not been so treated. The process is called *Transplanting* and plants which have been subjected to it are called *Transplants*, whilst those which have not are called *Seedlings*. The balance between root and shoot system in a transplant is also improved by the checking of height growth and shoot elongation, which occurs in the year following the transplanting. Both seedlings and transplants are used in the formation of woods. Seedlings are cheaper than transplants and where there is little trouble from weed-growth owing to the nature of the soil, the rapidity of growth of the species or the method of planting, small seedlings may sometimes be used with success.

The operations of transplanting and planting out should be performed in such a way as to minimise as far as possible any injury to the roots. However carefully carried out, however, the freeing of the roots from the original soil injures them and subjects the plant to a disadvantage, which in adverse conditions, may prove fatal. More especially, the tap root, which would normally penetrate downwards to a considerable depth and ensure supplies of water when the surface layers of the soil are dry, is often destroyed. Where moisture conditions are not too

adverse, however, planting of bare-rooted plants with reasonable care, is successful. Where drought is severe and it is imperative to avoid extensive injury to the root system, a small mass of soil containing the roots may be lifted with the seedling and transported to the area and planted. For this it is necessary that the nursery soil should have cohesive qualities and the extra weight and the care necessary in transport and handling add greatly to the expense. Moreover, it is difficult to avoid a certain amount of crumbling of the *ball*.

In more extreme conditions, growing the seedling in a receptacle, which is afterwards transported and sunk in the soil with the plant still undisturbed, is sometimes practised. The receptacle must be cheap and light and of such a nature that it will decay rapidly in the ground and form no obstacle to the subsequent penetration of the roots into the surrounding soil. Joints of bamboo, small baskets, etc., have been employed. This method is used in certain parts of India and the tropics.

Source of Plants.—The forester may raise his plants himself or he may obtain them from a trade nursery. The advantages of growing his own plants are (1) he can make sure that they are properly grown, if desired, from his own seed, and are of the right type, (2) being raised near the planting area, they can be delivered there in a fresh condition and the whole of the treatment to which they are subjected from lifting to planting is under his control. The chief advantages of buying plants from a trade nursery are (1) the exact number of plants required, of the right age and size can be obtained at short notice, whereas if plants are raised from seed, the number is less certain, and it is necessary to know three or four years in advance, what material will be required, (2) reliable nursery firms exist in many countries who have developed an efficient and economical technique, so that it is difficult in a small nursery to turn out material of equal quality more cheaply. In working on a large scale and in a systematic manner, with a regular demand for plants, a forest nursery is, however, highly advantageous. Where there are a number of forests or extensive forests under one management, it is generally found more profitable to have a few large nurseries than a number of small ones.

Forest Nurseries.—A Forest Nursery may be permanent or temporary. Temporary nurseries are made actually upon or close to the planting area. They do not require elaborate fencing, the soil is generally fertile enough to allow of cropping for the few years it will be in use, without manuring. As the plants are grown in proximity to the area to be planted, the cost of transport is minimised, and the plants are well acclimatised. This last advantage is felt especially at high elevations. In

working on a large scale it is usual to have both temporary and permanent nurseries. Often seedlings are raised in the permanent nursery and transplanted into the temporary one.

Permanent nurseries have their advantages and, as a rule, better plants can be raised in them, because they receive more attention. The permanent nursery can be located near the dwellings of the workpeople and more supervision exercised over operations. In a temporary nursery, the soil is more or less a matter of chance. The site of the permanent nursery is chosen with care and it is economically possible to improve the condition of the soil by cultivation and manuring. Buildings can be provided for storage of implements and appliances, for packing plants for transport, shelter for workmen, etc., and permanent or movable screens for protecting tender seedlings.

The object of the nursery is to raise plants, generally from seed, and nurse them through their early years so as *to fit them to be planted out on the forest area.* They should be given good soil conditions and protection from adverse climatic influences, weeds, diseases and enemies of the animal world. The principal processes which go on in the nursery are:

(1) Preparation of seed beds,
(2) Sowing of seeds,
(3) Protection of seeds and seedlings from frost, diseases, insects, mice and birds,
(4) Weeding of seed beds,
(5) Preparation of ground for transplants,
(6) Transplanting:
    (a) lifting of seedlings,
    (b) lining or pricking out,
(7) Weeding of transplant lines,
(8) Lifting plants and packing for transport to the planting area,
(9) Manuring.

It is not proposed to describe the technique of nursery work. It will differ in different conditions of climate, labour supply, etc., and the nature of the species dealt with. An efficient technique will reduce the losses at each stage to a minimum. Labour is the chief item in the costs and, keeping in mind that the whole object of the work is to produce material which is likely to grow well when planted out, weakly, diseased, and badly shaped plants are rejected when transplanting and when despatching plants. Manuring of the nursery is necessary, as young material is constantly being removed from it. While plants grow more vigorously in well manured soil, it is not advisable to force them into a rank and succulent growth, in view of the adverse conditions that will have to face when placed in their permanent positions.

Planting Out.—Planting out is the term reserved for the operation of planting on the forest area, whilst *transplanting* is a

nursery operation. The chief points to be considered in regard to planting out are:

(1) The season for planting,
(2) Arrangements and distribution of the plants,
(3) Care of the plants before planting.
(4) Methods of planting.

The *season* for planting depends on the climate of the locality. In temperate Europe, the summer is to be avoided because plants are assimilating and transpiring vigorously and are sensitive to changes in their conditions. Mid-winter, on the other hand, has also to be avoided in many cases, because of the occurrence of frosty weather, which not only makes the ground unworkable, but exposes the young plants to the danger of freezing whilst being handled and of drying by cold winds after planting. This leaves autumn and spring, when planting can be carried out at any time when the weather is favourable. Spring planting has the advantage that the young plants are not exposed to the winter storms and the attacks of animals before they have established themselves, and they begin to grow shortly after planting. On the other hand, autumn planting gives them a chance of making a certain amount of root growth before the soil becomes too cold, and so enables them to start better in the following spring. On the whole, spring planting is better with evergreen conifers, especially in exposed positions, whilst for broad-leaved trees, there is a certain advantage in autumn planting. When working on a large scale, both seasons are usually occupied. In most parts of India the beginning of the summer rains is the best time to plant, as the trees have the whole growing season before them.

There is a great advantage in arranging the plants in a uniform manner, so that the number and spacing of the plants is definite. The regular spacing facilitates *beating up* and weeding and the proper distribution of species in a mixture. At the same time too meticulous an adherence to a prescribed arrangement is inadvisable if it leads to the placing of plants in unsuitable spots or slows down the operations too much. The most usual arrangement is called *Planting on the Square,* the plants being placed in rows at a regular distance apart and the rows at the same distance as the plants in the rows. The growing space of each plant is then a square. An alternative method is known as *Planting on the Triangle,* in which each plant occupies the corner of an imaginary equilateral triangle, so that it is equidistant from each of its neighbours. For this the rows of plants are placed nearer together than the plants in the row. This means that for a given planting distance, more plants are required per acre than in the other method. Thus, at 3ft. planting distance, 4,840 plants are required per acre when planted on the

square and 5,590 when planted on the triangle. Planting on the triangle is more troublesome and its advantages are not great enough to justify its adoption in ordinary circumstances. Planting on the square is much more common. Another method is to have the rows wider apart than the distance between the plants in a row. This method is adopted when the ground is cleared of weed growth and cultivated in strips, in order to save expense and yet to have an adequate number of plants in case of loss.

Close planting has the advantage that the canopy is formed sooner and the loss of a few plants had no serious effect on the plantation. On the other hand, thinnings may have to be begun earlier and the material extracted is small and often of no value, so that besides the extra cost of plants and planting, further expense must be incurred. Too wide a planting distance, on the other hand, delays the formation of a canopy, permits of the branchy growth of individual trees, necessitates more careful replacement of failures and involves more weeding. The more exposed the site and the slower growing the species, the closer should the planting be. The usual planting distances in the case of the common conifers in Britain are as follows:

Common spruce	4-4½ feet.
Scots pine	4-5 feet.
Silver fir	4-4½ feet.
Sitka spruce	5-5½ feet.
Douglas fir	5-6 feet.
European larch	5-6 feet.
Japanese larch	5-8 feet.

It is highly important that the roots of the plants should be exposed as little as possible to the air pending the planting. Plants in transit should have their roots kept covered and, immediately on arrival on the ground, they should be *heeled in,* that is, laid with their roots in a shallow trench and covered with soil, in a position sheltered as much as possible from drying winds. When planting the workmen should not carry many plants in their hands, but should be supplied with them as required from a stock carried in boxes, canvas bags or the like, in which the roots are kept covered.

Methods of Planting.—The aim should be to give the young plant the best conditions for growth at the least expense. Some planting methods are cheap, in that it is possible to stick in a large number of plants in a day, but the results may not be satisfactory. The better the cultivation, as a rule, the better the results, but also the more costly the process. A suitable compromise should be arrived at and a method used which ensures a reasonable result at a reasonable cost. It is not necessary to ensure 100 per cent. survival if this can only be obtained at great expense. Certain methods are suitable for one set of conditions

and not for others. The nature of the soil, ground vegetation, climate and character of the species have all to be taken into account. The chief methods employed in Europe are: *Notching, Pitting, Mounding* or *Turfing,* and *Mattock Planting.* In *notching,* the idea is to wound the soil in a minimum of strokes (usually one or two) and thus make an opening quickly which is sufficient to take the roots of a small plant. No cultivation of the soil is attempted. In *pitting,* the soil is cultivated in a small patch or pit. In ordinary forestry it consists of removing a plug of soil about 6-7 inches in diameter with a few strokes of a spade, stirring up the bottom of the hole, placing the plant against one side of the pit and bringing loose soil against it to hold it in position and then breaking up the plug, filling the hole and forming with the heel. Various types of spade have been devised for doing the work, such as: the Irish, the circular, and semicircular spades, etc. On steep slopes and rocky soils, the mattock is a more suitable tool than the spade. *Turf planting* is employed on peat soils. Here the chief trouble is the poor aeration of the soil owing to the great water holding capacity of the peat. The principle of the method is to carry out a complete system of draining and to use turves cut from the drains as mounds on which the plants are planted. This gives the young plant a bit of well-drained and aerated soil to start with, and by the time it requires to extend its roots into the surrounding ground, the drainage will have had time to bring about improvements in the conditions.

The process of replacing any plants which have failed to grow after planting is known as *beating up.* If the planting has been reasonably close and the number of failures is small and confined to an odd plant here and there, it may be unnecessary to replace the dead plants because the few small gaps present will be quickly closed by the growth of surrounding plants. If, however, there are many losses and especially if they have occurred in groups beating up is necessary. It should be done in the next planting season, so that the new plants will have a chance to hold their own with their neigbours. If the process is delayed it may be necessary to employ another species, either a faster growing one or one which will withstand the shade of the plants already established.

(b) Planting of Cuttings, Sets, etc. — Certain species of trees can be grown more easily from cuttings and sets than from seed. Cuttings are parts of shoots and sets are whole shoots, including the top, and they are placed with the lower end buried in the soil. Roots are formed on the underground portion of the cutting or set. Cuttings may be lined out in the nursery and planted after they have made one or two years' growth, but

they may also be placed directly in the ground on which they are to grow. The chief species in European Forestry to be raised by cuttings and sets are the Willows and Poplars. These species grow readily when propagated in this way, whereas the raising of them from seed is often difficult or impossible. Both these genera are *diœdious, i.e.* the male and female flowers are on different trees and in some of the valuable hybrids only one of the sexes is known. Moreover, such hybrids will not breed true, so that it is only by vegetative means that the desired kind of tree can be propagated. Moreover, the seeds are very small and the raising of seedling plants difficult and slow. Vegetative means of reproduction are also practised with special varieties and forms of trees and shrubs of other species, but these do not come into consideration in Forestry in Europe.

III. COMPARISON OF THE DIFFERENT METHODS OF REGENERATION

Natural and Artificial Regeneration, Sowing and Planting have advantages and disadvantages whose relative importance differs according to circumstances. Brief notes on some of the most important are given below.

It is claimed for natural regeneration that it is preferable because it is the natural way and so is likely to lead to healthier and better woods. It has, however, already been remarked that the so-called natural regeneration in forests worked for timber is not a true reproduction of the process by which nature keeps the forest in being. Regeneration in nature is a very slow process, keeping pace with an equally slow elimination of older individuals from the forest community. In worked forests, on the other hand, there is a much more rapid removal of individuals and the regeneration process has to be hurried in order to replace them. Nevertheless, the form of woods and the method of treatment associated with natural regeneration maintain a more continuous and better cover on the ground than the clear felling generally associated with artificial regeneration.

Natural regeneration ensures the maintenance of the race suited to the local conditions. This advantage is receding in importance nowadays owing to the care exercised in obtaining seed of suitable origin and may, indeed, disappear all together if the utilisation of seed from selected *trees* is proved by experiment to produce better crops.

When natural regeneration is very successful, the immense number of seedlings produced causes the struggle for existence to set in early and the natural selection of the fittest to go on vigorously. The young trees are well drawn up and clean timber is more likely to be produced. On the other hand, a certain amount

of artificial selection is practised at the various stages in raising plants and planting out, the feebler, badly formed plants being rejected. The close crops produced by natural regeneration are, however, specially advantageous in the case of species prone to branchy and crooked growth, *e.g.* oak.

In natural regeneration the expense of collecting seed, raising plants and planting is avoided. Against this saving must be set the cost of cultivation of the ground, weeding and protecting young seedlings, the damage done to young growth by felling and removing shelter trees, and the extra cost of exploitation of the old crop as compared with clear felling.

The dependence of natural regeneration on local seed production and the consequent irregularity in the progress of regeneration and the harvesting which is dependent on the latter, is a serious drawback, especially in the case of species which only bear fruit at comparatively long intervals. Owing to irregularity in the distribution of seed the young crops are apt to be irregular and a certain amount of artificial help has generally to be given to complete the stocking.

Natural regeneration is more difficult to manage and requires greater intelligence, skill and care on the part of the forester and the workpeople than artificial regeneration. On the other hand, it is much more interesting and its practice leads to a fuller understanding of the complicated life of the forest community than the rather monotonous and stereotyped technique of clear felling and planting.

The advantages and disadvantages of *Sowing* and *Planting* are rather more definite. Sowing may be expected to lead to a more natural and satisfactory root development of the plants, though it is doubtful if the power of adaptation of plants is not sufficient to eliminate injury to the root system in the majority of cases. The crops produced by sowing may be much denser than those raised by planting, so that competition is more intense with the results mentioned under natural regeneration. Sowing is quicker than planting and may have to be adopted when large areas have to be afforested or regenerated rapidly, as after a fire, wind storm, etc., and suitable stocks of plants are not available. It is cheaper than planting, only if the cost of raising plants and planting is not exceeded by extra cost incurred in cultivation of the soil, and the protection of young seedlings (weeding, spraying against diseases, etc.), which are more easily damaged than larger transplants. The seeds themselves are exposed to the attacks of birds, mice, insects, etc.

In practice, sowing will be confined to more favourable conditions, whilst planting will be employed where weed growth, drought, etc., are to be feared.

5. ESTABLISHMENT OPERATIONS

After the young crop has been started on the area, either by seeding or planting, attention must be given to it to prevent the small plants being smothered by weeds. The methods of dealing with the weeds must be adapted to the particular nature of the weeds themselves and will be briefly discussed under Forest Protection. Other protective measures against injurious animals (fencing, trapping of insects, etc.) and fungal diseases (spraying against leaf-shedding diseases, etc.) may have to be carried out.

Treatment of Advance Growth.—Advance Growth consists of plants or coppice shoots of the previous crop, which have made their appearance before the planting or seeding, and have got a start of the main body of young plants. The treatment of advance growth varies according to its nature. Rank, badly formed single trees and small groups of seedlings or coppice shoots which stand up abruptly above the general level of the young crop should be removed, otherwise they will become coarse and widely branched. Groups of young trees of good form which have not obtained too great a lead in height growth may sometimes be retained with advantage, especially if they consist of valuable mixing species such as ash, sycamore, etc. Worthless softwoods, such as birch and willows, should, however, be cut out. Some systems of natural regeneration are better adapted than others to make use of advance growth. When the system is such that groups of advance growth may be taken in hand before they have made much height growth and extended gradually by successive regeneration fellings round their margins, they can be made to merge satisfactorily with the remainder of the new crop. Such groups will have a dome-like rather than a spire-like contour and none of the trees in them will have an opportunity of spreading their crowns unchecked. In unfavourable localities such as high elevations where seed bearing is unsatisfactory and regeneration difficult, advance growth is retained, which in more favourable conditions would be eradicated.

Apart from advance growth, the cuttings made in the establishment stages are chiefly of species of plants not intended to take part in the formation of the future wood. After the crop has grown for some time danger from most kinds of weeds is over, liability to wholesale destruction by frost overcome and the wood may be said to be established.

6. THE TENDING OF WOODS

Under the tending of woods are included all the silvicultural operations between the establishment of the crop and its final

harvesting or the starting of new regeneration, which have for their object the up-bringing of the wood, *i.e.* the guiding of its composition and growth so as to fulfil, as far as possible, the objects of working.

In the main, but not exclusively, these operations consist of attacks on the crop; the cutting down and removal of individual members.

The tending operations may be classed as follows:

1. Weeding or cleaning.
2. Thinning.
3. Light Fellings or Partial Clearances.
4. Pruning.
5. Underplanting.

(a) Weeding or Cleaning

By these terms are meant those cuts made in young growth which are purely cultural and generally provide no useful material. They take place before the young crop has entered the dense, thicket stage when it is impossible to work in it, and it must be left to itself for a number of years. Individual trees which, if left, would damage their more valuable neighbours are cut out, including any advance growth, vigorous coppice shoots or useless softwoods which have remained uncut. Moreover, hardy species, grown for the temporary protection of sensitive ones against frost may be removed at this time. In mixtures, individuals of valuable light demanding species have to be freed from the encroachments of aggressive shade bearers. For example, in a mixture of oak and beech, it is essential that the oaks should not be overgrown by the beeches, and where there is a danger of this happening, it is necessary to free the desirable oaks by cutting back the encroaching beeches round them. This ensures that the oaks have a chance of surviving through the thicket stage, until they can be again looked after. If this freeing of the young growth is neglected in such circumstances, the crop will be irretrievably ruined. The operation must be carried out by experienced and reliable men.

(b) Thinning

Thinning begins after the thicket stage has been passed through and the effects of competition on the crop have had time to show themselves. These effects are evident in the reduction in the numbers of the living members of the crop, the form of the trees and the density of the canopy. It has already been explained that the effects of competition and co-operation in the tree community are to cause the trees to develop clean stems, free from living side branches, and narrow crowns, confined to the

upper part. The cramping of the crowns restricts the leaf surface and hence the assimilation of the individual tree, so that the stems, on the average, grow only slowly in diameter.

As time goes on, the less vigorous trees are progressively overgrown by the more vigorous and are left behind as the canopy rises higher and higher above the ground. The surviving trees are tall, with long, comparatively slender stems. In the primeval forest, after a very long time, the survivors may have massive as well as long boles, whilst the numerous individuals which fail to survive fall victims to decay and the attacks of insects.

In economic forestry, it is not possible to wait long enough for the slow process of nature to build up the massive stems required by industry, nor is it justifiable to leave the unsuccessful competitors in the struggle for existence to die and decay. Moreover, the trees which would survive naturally, are not necessarily those which are most desirable from an economic point of view. The tree which asserts its dominance early may develop a broad crown and branch comparatively low down, it may have a crooked or forked stem or be of a less desirable species than its slower-growing neighbours.

By the process of thinning, the forester intervenes in the competition in order to guide the development of the wood in composition and constitution so as to ensure the production of a stand consisting of trees of the right species, of good form and adequate dimensions, in as short a time as possible. This he does by cutting down trees which are harmful and those which are no longer of use from this point of view. According to modern ideas, therefore, the main object of thinning is to produce effects on the crop that remains after the cut, and the realisation of the value of the material extracted in the process is only secondary.

Thinning has been the subject of great controversy during the last fifty years or so. In the past, it was the practice in Britain to thin woods when the branches of the trees began to interfere with one another and, as a result, widely branched, low-crowned trees were raised and the forester had to resort to pruning in order to get cleaner stems. The demands of the Royal Navy for oak for ship building, which it was the great object of British forestry to supply, included crooks and elbows which the massive crowns of trees grown in this way provided. This type of thinning had therefore some justification for this particular purpose, but when it was applied to other species and for other purposes it was very unsatisfactory. Nowadays, even with oak, clean stem timber is required, and British foresters have come to recognise the advantages of the *Natural Pruning*

which goes on in closer woods, of which continental foresters have always made the fullest use.

On the Continent, the development of thinning practice has been rather the other way. The earlier foresters were obsessed with the necessity of maintaining the canopy unbroken and, as a rule, removed only the suppressed, dying and dead trees. Such thinning can hardly be said to have aimed at anything beyond the harvesting of material which would otherwise have been left to decay, though considerations of disease and insect breeding places may have had some weight. More recently, heavier thinnings, involving temporary breaches in the canopy, have gradually been adopted, though they have not reached the extreme of the older British practice. In particular, young woods are kept much more dense than was the case in Britain.

If thinning is to influence the future development of the wood, it must affect those trees which will form the crop of the future, especially those which will form the final crop. The survival of a tree and its course of growth depend, in the main, on neighbouring trees of equal or greater size and vigour. It is they which enter into competition with it and affect not only its growth in general, but also its form. Trees which have been overgrown and suppressed have little or no power to injure their larger neighbours and their removal can do the latter no good. The future of the wood belongs to the trees which have their crowns in the upper canopy and thinnings made in order to guide the development of the crop and maintain a suitable mixture must therefore be made among them.

Besides affecting the nature of the crop by selecting the trees which are to be favoured at different stages, thinning has also certain other effects which may be briefly discussed. It may influence the soil favourably or unfavourably according to circumstances. By the admission of more light, a ground vegetation may develop which appropriates too much of the soil moisture and nutrients or through the nature of its debris produces raw humus. On the other hand, in dry soils, the reduction of the number of trees may lead to better moisture conditions, provided a water consuming ground vegetation does not make its appearance. Again the admission of light and heat may promote the decomposition of raw humus.

Thinning also has an influence on the susceptibility of the crop to certain dangers. A systematically thinned wood is generally less liable to snow and storm damage than an unthinned one; but if the danger arises soon after a thinning has been made and before the trees are able to respond to the opener stand, the damage may be increased. This is, however, particularly the case when thinning operations have been delayed, so that long,

slender stems with small crowns and inadequate root systems have been produced. The removal of dead, dying, diseased and insect infested stems reduces the danger of infection.

The effect of thinning on volume production is difficult to assess. The number of stems putting on increment is reduced by thinning. The effect is to concentrate production on fewer stems, which generally grow more rapidly in the more open stand. The advantage of this is that marketable dimensions are reached sooner, but if the thinning is too heavy, not only is the total volume production reduced, but the trees tend to become branchy and their value per unit volume is diminished in consequence.

The thinning of a wood should have a definite object and the method must be based on the constitution of the wood and the course of its development. Generally speaking, the object is to raise clean stem timber of adequate length and diameter in the shortest time possible. Length, straightness and cleanness of stem are promoted by growth in a close stand, whilst diameter increment is promoted by an open one. Length and cleanness must be obtained first because the diameter increment is added to the previously existing stem which must therefore be of suitable length and shape. In general, therefore, woods are kept rather dense when young by thinning them lightly, and gradually opened up later to promote diameter growth, when the desired length of clean stem has been attained. There is room for great variation in the treatment, according to the relative stress laid on length of bole, freedom from knots, regularity and width of annual rings, diameter, etc., in the given case.

The responses of different species to thinning are not the same. Species vary in the amount of crowding they will stand without injury through the constriction of the crowns of individual trees, and in their power of recovery when more open conditions are afforded by thinning operations. Thus, the oak is apt to suffer permanent injury if its crown is restricted too much, whilst the beech responds markedly to thinning operations. Similarly, the spruce is slow to recover if its crown has once been crippled by side shade, whilst the silver fir has considerable power of recuperation in similar circumstances. Whilst height growth and straightness of stem are promoted by close stand in broad-leaved trees, with some conifers (spruce, silver fir, larch) the stems are naturally straight and, so long as the branches are touching, height growth is not increased by further crowding. With the pine, however, a reasonably close stand is required to prevent the premature breaking up of the stem into branches.

These examples show that the different species require different methods of treatment and thinning demands consideration of the species and the density of the wood as well as of its con-

stitution out of trees of various classes and the course of its development.

Classification of Trees in a Wood.—The trees in a wood allowed to grow undisturbed, show a gradation from well developed, strong growing individuals, through the gradually feebler and more backward, to the dying and the dead. According as to whether their crowns take part in the formation of the upper canopy or not, trees can be divided into two great classes: Dominant Trees (Main Crop) and Dominated Trees (Secondary Crop). There is no sharp distinction, however, between these two classes. During the life of the wood, trees are constantly passing from the main crop into the secondary crop and, much more seldom, *vice versa.*

The classification of trees in woods for the purpose of defining grades of thinning, was first done by Krafft, of Hanover, who published his work in 1884. Krafft's classes were distinguished only by the nature and position of the crowns of the trees. Later workers have introduced sub-divisions of Krafft's classes according to the form of the *stems* and the practical importance for the future development of the wood, of various members of the two groups, Dominant and Dominated Trees.

The following is the classification adopted by the International Congress of Forestry Research Institutions in 1903:—

I. DOMINANT TREES (Main Crop) taking part in the formation of the upper canopy.
   (1) Trees with normal crown development and good stem form.
   (2) Trees with abnormal crown development *or* bad stem form.
      (a) crippled stems, (b) badly formed advance growth, (c) other trees with faulty stems, such as double leaders, etc., (d) whippy stems whose crowns beat against others in wind storms (whips), (e) diseased trees of all kinds.

II. DOMINATED TREES (Secondary Crop) not taking part in the formation of the upper canopy.
   (3) Backward trees which are still not overgrown.
   (4) Suppressed trees; overgrown but still capable of life.
   (Both classes of value for soil and crop management).
   (5) Dying and dead trees, no longer of use for soil and crop management, bent down poles, wind thrown trees, diseased trees.

Owing to the actual considerable variation in the relative position of the crowns of trees which may be classed as *dominant* and the great importance of the group as a whole, some workers urge that further sub-division of the Dominant Trees should be introduced, *e.g.* over-dominant, dominant, co-dominant, etc., with the necessary sub-classes according to stem form. As it is not proposed in this book to do more than indicate the principles on which thinning is based, however, there is no need to complicate the table.

Systems of Thinning.—The system of thinning practised in Krafft's time and for a long time afterwards began with the removal of the suppressed and dying trees, and gradually increased in severity until the whole of the dominated trees were removed, always on the principle of sparing the dominant trees and preserving the canopy unbroken. This form of thinning is known as *Thinning from Below.*

According to later ideas, the still living trees of the secondary crop are not necessarily valueless for the further development of the wood. They may be of use in cleaning the stems of the quicker growing trees of side branches and preventing the formation of adventitious shoots on them, and also in protecting and enriching the soil. They are, moreover, of low sale value, so that they should be allowed to remain in the wood, so long as considerations of protection do not call for their removal (fire and insect danger in conifers). On the other hand, great stress is laid on the removal of *dominant trees* which are of undesirable form where they are actually prejudicing the growth of better formed neighbours. Moreover, it is considered necessary to relieve the crowded condition of groups of trees of fairly similar character by removing one or more of the less well formed individuals, as otherwise the growth of well developed crowns is impossible. Finally, all diseased trees, wind thrown stems, bent down poles and trees which rub the bark of their neighbours, causing bark wounds and malformations, should be constantly removed. This form is known as *Thinning from Above.*

The essential difference between *Thinning from Below* and *Thinning from Above* lies in the systematic preservation of healthy members of the secondary crop in the latter system. Nowadays the strict preservation of the canopy by carefully avoiding any attack on the dominant trees has been given up in *Thinning from Below.* However, cuts in the dominant crop cannot be made so freely in this system, because there is no secondary crop with many trees capable of development to clean the stems and protect the soil.

In thinning young woods, the first question is: what trees should be removed on account of their own bad character and their danger to their better formed neighbours? The worst trees from this point of view are often the extra vigorous, branchy specimens, which, if left alone, would get their heads above the general level, spread abroad their crowns and play havoc with more promising trees around them. The removal of these aggressive, so-called *wolf trees* is one of the most important tasks in the early thinnings, if quality, as opposed to mere volume production, is the object to be sought. The importance of this procedure is not equally great with all species and in all

circumstances. With many conifers—silver fir, spruce, larch—the largest trees are not generally of bad shape. They are, on the other hand, the quickest growing and the soonest to reach marketable dimensions. With broad-leaved trees they are apt to be heavily branched and their stems tend to divide fairly low down. With the pine and Douglas fir, also, the dominance of such trees is so quickly asserted that they extend their branches and the timber becomes very coarse and knotty. In young woods it is not desirable to reduce the competition between the members of the crop unduly, as on it depends the production of clean straight stems. Thinnings are therefore light in character.

In thinning older woods, the procedure is rather to select the best trees and remove all those which interfere with the development of their crowns. By this time, the crop should consist mainly of trees of good form and a satisfactory length of clean bole should have been attained. The object now is to promote diameter growth by increasing the leaf-surface, and, in cases where natural regeneration is relied upon, to build up crowns capable of producing adequate quantities of seed later on. These objects are attained by giving the trees more room than was desirable in the earlier stages. At the same time it is not desirable to reduce the number of trees too quickly so that the canopy is so far destroyed as to encourage the appearance of a harmful ground vegetation, or of adventitious shoots on the stems of the remaining trees. Moreover, as has already been stated, the excessive depletion of the growing stock may reduce the total increment unduly.

Throughout the history of the wood, the suppression of trees by the spread of the crowns and roots of their quicker growing neighbours and the development of bad stem and crown forms goes on, so that thinning has to be repeated periodically. The interval between two successive thinnings must be the shorter the more energetic the growth and the lighter the previous thinning. They are therefore repeated more frequently in young woods than in older ones.

In thinning mixed woods, the more valuable species are favoured at the expense of the less valuable. The system of thinning from above gives the best opportunity of meeting the claims of individual species. Especially is this the case where a valuable light demander is mixed with a shade bearer, *e.g.* oak with beech. The dominant beeches are sacrificed where they are interfering with the best oaks, whilst the dominated beeches are retained for cleaning and soil improvement purposes. In other cases, the retention of healthy members of the dominated crop has theoretically much to recommend it, but it is often found in practice that the dominated and suppressed trees will not

survive very long. With light demanders they die very quickly. Where the dominated trees fall behind very rapidly and dying and dead material tends to bulk largely at the end of the thinning period, there is no great advantage in retaining them. For many conifers, especially the pine, thinning from below is the more suitable system.

(c) Light Fellings

In ordinary thinnings the breaches made in the canopy are only temporary. The crowns of the remaining trees are expected to close the gaps within a comparatively short time. In certain cases, however, cuts are made in the crop which go beyond even the heaviest thinning and involve a permanent opening of the canopy. These cuts may be called *Light Fellings*. They are made with the object of raising large timber without prolonging the rotation unduly, by taking advantage of the increased rate of growth in diameter generally shown by trees which are more or less isolated and have room to spread their crowns. This increased growth is generally called *Light Increment,* but it is improbable that it is due entirely to increased access of light. Opening up of the crop reduces root competition, permits more of the precipitation to reach the soil, increases soil moisture and promotes the rapid decomposition of humus, whereby increased supplies of minerals and nitrates are made, at least temporarily, available for the remaining trees. Light increment is generally greater with shade bearers than with light demanders and with young and middle-aged trees than with old ones. Light fellings are employed especially with species which have a particularly high value in large sizes, notably oak. In order to avoid unfavourable effects, such as adventitious shoot formation (oak), wind fall (spruce) and bark scorch (beech) it is better to lead the woods over into the open conditions by a succession of fellings rather than by one heavy cut.

Owing to the great reduction in the number of stems, the *total volume increment* of the stand is never increased by light fellings, which generally remove from ¼ to 1/3 of the crop in a short period, say ten years. Whether the *value* increment is increased depends on the prices realised for the large timber assortments in question. In any case, the method should be employed only with faultless trees with good crowns and in good localities. In order to avoid deterioration of the soil, it is necessary to establish an underwood.

(d) Pruning

Pruning in silviculture is the artificial removal of branches close to the stem in order to obtain clean timber, free from large

knots, when the natural shedding of dead branches is not sufficient for the purpose. Pruning was at one time freely resorted to in British woods and also on the Continent in the system of silviculture: *Coppice with Standards*. The standards, which are grown rather wide apart, produce short boles, branching low down, in the absence of artificial pruning. With the falling out of favour of this system of silviculture and the growth of denser woods, pruning ceased to be practised in ordinary silviculture, but more recently, with heavier thinnings, it has once more come to the fore.

In forestry, pruning is almost entirely confined to the removal of dead branches, so-called *dry pruning*. *Green pruning*—the removal of living branches—is only done as a rule for special purposes, such as the removal of branches overhanging roads or buildings or endangering telegraph wires, etc. Some foresters do, however, advocate the extension of pruning into the lower part of the living crown, provided the branches are small and their foliage assimilating feebly. Kienitz found that the removal of the lower, shaded branches of spruces actually increased the rate of growth of the trees, presumably because the water and soil nutrients they had been using up were more usefully employed by better lighted branches above them.

However, the pruning of living branches is of more doubtful advantage than the removal of dead ones and should be done with caution, as not only does it reduce the effective leaf surface, but causes a wound through which disease may find entrance. On the other hand, the pruning of dead branches is always an advantage from the point of view of the quality of the timber, provided the branches are not too large, and the chief consideration is the cost. In order to reduce this as much as possible, pruning should be confined to a number of the best stems, suitably distributed over the area, which may be expected to remain to the end or nearly to the end of the rotation. To be of any real value in raising the quality of the timber, pruning must be done early and repeated two or three times as the height of the stem increases, so as to reduce the knotty core of the stem to a minimum for as great a height as is economically possible. The tree must be given time to put on a good thickness of clean wood outside this core.

Care should be taken to remove branches flush with the stem, avoiding injury to the bark and cambium round the wound. Pruning of branches over two inches in diameter is not ordinarily done, when the object is to improve the timber. When larger branches are removed, the wound should be dressed with an antiseptic material such as coal-tar, especially in the case of broad-leaved trees. Pruning is generally done with saws, either

pole saws or handsaws, the latter being used from a ladder where necessary.

(e) Underplanting

By underplanting is meant the establishment of a second crop under one already growing. The objects and merits of this procedure are discussed later under the silvicultural system *Clear Felling with Underplanting.*

7. THE SILVICULTURAL SYSTEMS

A Forest, in the narrower, technical sense, is a collection of woods organised for providing timber and other products. We have already discussed the characteristics of different kinds of woods — large and small, pure and mixed, even-aged and uneven-aged—and also the different methods of regeneration. The nature of a wood, though it may be modified by subsequent treatment, is largely determined by the way in which it originated, *i.e.* the method of regeneration practised. Different methods of regeneration are associated with different methods of harvesting the mature crop, as the time and place of the fellings is influenced by the requirements of the new one. Exploitation, regeneration and the nature of the woods are all interdependent. A Silvicultural System is a method of exploiting the crops in the forest and replacing them by new ones, resulting in the production of woods of a distinctive form.

The Silvicultural System, besides determining the nature of the different woods in the forest, has also an influence on their arrangement, because considerations of protection against wind, sun, etc., have to be given weight in determining the order and direction of the felling and regeneration processes. In general, however, the organisation of the woods, their size, and the arrangement and distribution of the age classes on the forest are in the province of Forest Management, which is concerned with the regulation of the yield of the forest as a whole.

If account is taken of all the details of tending, felling and regenerating woods, the number of silvicultural systems is very large, but it is possible to group most of them into a few main systems. The following scheme, though it does not include every system, is sufficiently comprehensive for our purpose.

- I. HIGH FOREST. Crops normally of seedling origin.
  - A. Clear Felling.
    - (1) Without underplanting.
    - (2) With underplanting.
  - B. Regeneration under a shelterwood.
    - (1) New crop even-aged and uniform.
      - Uniform or Compartment System.

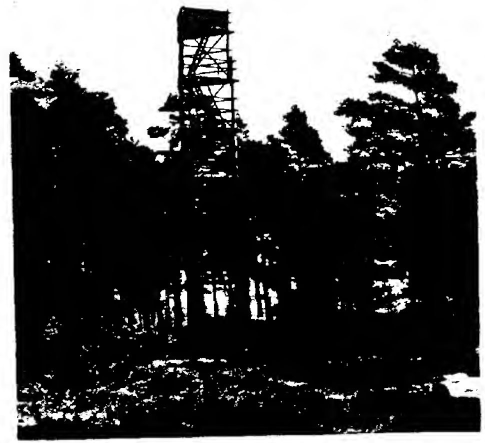
PLATE II.

To face page 96

A

Natural regeneration of Scots Pine. (New Forest, England.)

See p. 71.



B

Look-out tower for fire protection. (New Forest, England.)

See p. 115.

(2) New crop uneven-aged when young but becoming more or less uniform later.
    (a) Group and Irregular Shelterwood Systems.
    (b) Strip Systems.
    (c) Combined Systems (Strip and Group).
(3) New crop uneven-aged throughout its life.
    (a) Age classes mixed over the area: Selection System.
    (b) Age classes arranged in order: Border cutting systems.

II. COPPICE. Crops originating from stool shoots or other vegetative means.
    (1) Simple Coppice.
    (2) Coppice Selection System.
    (3) Pollarding, etc.

III. COPPICE WITH STANDARDS. Crop consisting partly of vegetative shoots, partly of trees, generally of seedling origin.

I. THE HIGH FOREST SYSTEMS

The distinguishing characteristic of High Forest is that all the trees have originated individually from seed. The seed may have fallen naturally on the ground or have been sown artificially direct in the forest or in a forest nursery, from which the resulting plants have been brought on to the area. The High Forest Systems generally aim at the production of high trees and large timber, but not necessarily so.

A. Clear Felling

(1) Without Underplanting.—In the clear felling systems, the whole of the crop standing at maturity is felled and removed, and regeneration take place on the cleared ground. The term "Clear Felling" is only applicable when the areas cleared are not so small that the influence of the adjoining stand determined the conditions. Actually the felling of a single tree in a wood is a clear felling on a very small area, but the presence of the remaining trees exercises a dominant influence on the climate and soil of the site. Similarly a system in which very narrow strips are cleared along the margin of a wood is not technically a clear felling system, but a "Shelterwood System" because the sheltering effect of the neighbouring stand governs the conditions. Subject to the above considerations, the areas cleared at one time in the Clear Felling System may be large or small. Regeneration may be natural (from seed already present in the soil), but in the vast majority of cases it is carried out artificially by planting, or by sowing seeds. In its pure form the system leads to even-aged woods, with their advantages and disadvantages.

In favourable conditions the young plants benefit from the uninterrupted light and freedom from root competition from trees of the previous crop. The operations of exploitation are concentrated and are not hampered by fear of damage to young growth or to trees which are to remain standing.

The chief drawback to the Clear Felling System is the exposure of the soil and the young regeneration to the weather. Sun, rain and wind affect the soil and may cause deterioration through leaching, drying out, destruction of humus, etc. The young plants are exposed to frost and drought. On rich soils weeds spring up and grow vigorously, necessitating expensive cleaning operations. The importance of these drawbacks differs considerably in different cases. In mild, equable climates with an ample and well distributed rainfall, it is possible to establish in the open, species which are too sensitive to frost and drought to be raised in this way in more extreme climates. The simplicity of the operations associated with the clear felling system and its economic advantages have led to its adoption on a large scale in regions and with species for which it is suited. In Britain the system is successful with many species which, on the Continent, are generally found to be too sensitive.

Clear Felling is so closely associated with artificial regeneration that, in general, when the term is used unqualified, it is assumed that artificial regeneration is implied. The system, therefore, generally offers the advantages and disadvantages of artificial regeneration, which are discussed elsewhere (p. 84).

(2) Clear Felling with Underplanting.— In this system a beginning is made in the same way as in that described above, and the crop, which consists of light demanding trees, is allowed to grow on for a number of years as an even-aged stand. A second crop is then introduced under the first, generally by planting. The two crops grow in together to maturity and are both felled at one time. The object of the system is to obtain some of the advantages of a pure wood of light-demanding trees and avoid some of the disadvantages. In the earlier stages such a wood is able to maintain a good cover on the ground, the stems are well drawn up and the maximum number of individuals is present from which the forester can select the best to grow on. The drawbacks of a pure wood of light demanders (opening of the crop, soil deterioration, weed growth, bad development of stems, etc.) only set in later and the underwood of shade bearers is introduced in order to mitigate them. The additional advantages claimed for the system are:

(1) Early returns are obtained, not only from the heavy thinnings made in the overwood at the time of underplanting, but also from those made possible afterwards by the protective effect of the underwood on the soil.

(2) The best stems of the overwood increase rapidly in size and value as the result of such thinnings.

(3) Shelter is given by the overwood at the time of planting, to the shade bearers which are generally sensitive to frost when young.

(4) The difficulty of maintaining an even-aged mixture of a light-demander with a shade-bearer is avoided by giving the former a start.

(5) The general advantages of a mixed, two-storied wood are obtained.

Besides the drawbacks associated with clear felling as such, this system has certain disadvantages of its own. The drastic opening of the original crop, necessary at the time of introducing the underwood, may lead to serious damage by wind. Since both crops are to be felled together, the underwood must be given time to reach marketable dimensions if it is to produce an additional income. This necessitates a long rotation for the overwood, especially as the underwood is kept back by the shade. The system is therefore most suitable when the overwood consists of a valuable light-demanding species which requires a long rotation, *e.g.* oak.

Occasionally, however, the underwood is expected only to improve the soil and the growth of the overwood, and not itself to provide valuable material. It is then termed a *Soil Protection Wood*. A variation of the system is when the underwood springs up naturally from seed blown on to the area or falling from a few seed trees in the original crop. By thinning the overwood heavily and cutting out any shade-bearers in it, a crop of seedlings arising in this way may be established.

B. Regeneration Under a Shelterwood

In these systems, instead of the whole of the trees standing in the wood being felled at one time, a portion of them are left standing to act as shelter to the young crop, being removed later when the latter is able to do without such protection and demands more light. The exploitation of the mature trees therefore takes place in stages. Generally speaking, the management of the shelterwood is directed towards the production of natural regeneration by seed, but it is often necessary to supplement it by artificial regeneration and in some cases to rely on artificial regeneration entirely.

In the table given above the shelterwood systems are classified according to the constitution of the woods they produce. The constitution of a wood depends in the first place on the range of age classes represented in the crop. Where the range is very short, there is little difference in height of the trees after the

earliest years, and for practical purposes the crop is even-aged throughout its life. Woods of this kind are produced by the Clear Felling system and by Shelterwood Systems in which the young crop springs up rapidly and uniformly over the area, and the shelterwood is retained only for a short time.

If the range of age classes is somewhat longer, the uneven-aged character of the wood persists for a longer time, but if it is not excessive compared with the time required for the trees to reach maturity, the wood becomes uniform in height (even-aged) in later life. This more extended range of age classes is produced by systems in which regeneration does not proceed simultaneously all over the wood, but is carried out in parts of it in succession so that the regeneration in some places is not started until after it has been completed in others. The exploitation of the old trees is thus spread over a longer period of years, known as the *General Regeneration Period,* but this period occupies only a part of the life of the wood. It is succeeded by a period, generally of considerably longer duration, in which no regeneration is attempted. In forests worked under these systems, therefore, the exploitation of mature trees and regeneration are confined to certain woods.

Finally, in certain systems, the range of age classes is complete. Trees of all ages, from seedlings to mature trees, are present within limited areas. Such woods are produced by systems in which exploitation and regeneration are going on all the time in every part of the forest.

In comparing the merits of different systems from an economic point of view, it must be remembered that in an organised forest the total annual yield of timber is fixed and controlled. Since in the shelterwood systems the whole of the mature crop in a given area is not cut in one year, the annual yield of the forest must be sought over a larger area than if it were obtained by the clear felling of mature woods.

(1) New Crop Even-aged Throughout.— Here the object is to establish the young crop uniformly and as rapidly as possible over the whole wood or a large part of it. The system is therefore called the *Uniform* or *Compartment System.* The successive fellings in the old crop are carried out so as to produce as far as possible uniform conditions of lighting, shelter and soil. The ideal is to obtain the bulk of the regeneration from the seed of a single year. Supplementary seeding from the shelterwood trees, aided by planting, should fill up the gaps rapidly so that the new crop is practically even-aged and as uniform in height and development as possible throughout its life. The exploitation of the old trees, if all goes well, is therefore carried out in a few stages (seed felling, secondary fellings and final felling)

over a comparatively short period of years, *i.e.* the time required for the young growth to reach a stage when shelter is no longer necessary. The felling operations are more concentrated in this system than in any other except clear felling, and, in favourable cases, the simplicity of the subsequent treatment and the high quality of timber associated with even-aged woods also characterise the Uniform System.

The system is, however, subject to a number of drawbacks, of which the following are the chief:

(1) Its dependence on the occurrence of good seed years. There will be a tendency to make extensive fellings in such years and so to throw on the market larger volumes of timber than usual with a consequent depression of prices. This is particularly the case with species which only bear ample quantities of seed at long intervals.

(2) The risk of soil deterioration, weed growth, etc., if adequate regeneration does not appear after the old crop has been opened up, making subsequent regeneration difficult.

(3) Damage done to young growth by the felling and removal of shelter trees, which have to be drawn out considerable distances.

(4) Danger of wind throw in the shelter trees which are isolated over a considerable area on which they can receive little or no protection from adjoining stands.

(5) The uniformity of the conditions over the area favours the regeneration of a single species. The system therefore makes for pure woods with their accompanying drawbacks where regeneration is really successful. It is only where the system is not really successful, and uniform conditions are, in fact, not achieved, that mixed woods are obtained. In most cases valuable mixing species (*e.g.* oak) have to be given artificial help by planting in blanks.

Since in the Uniform System the exploitation and regeneration of the forest are concentrated in a few, comparatively large areas, the risk of failure is more serious than in systems operating in more numerous but smaller units. It therefore requires favourable conditions and is most suitable for pure woods of shade bearers which are not particularly susceptible to wind damage. It is not suitable for light-demanding trees, for mixed woods, for species prone to severe and permanent injury through the felling and extraction of shelter trees, and generally for unfavourable conditions and poor soils. It has been practised most successfully with the beech, but tends to be modified nowadays into a more irregular form, in order to permit of the regeneration of other species, such as oak and ash, in mixture with the beech to improve the money yield from the woods.

(2) **Crop Uneven-aged when Young, but more or less Uniform later.** — In these systems the idea of uniform regeneration is abandoned and the opening of the old wood is carried out in some parts of the area before others, so that young growth is started and established in different places successively until the whole wood is regenerated. The range of age classes in a wood established in this way will depend upon the period of time which elapses between the beginning of regeneration in the first and the last parts taken in hand. This range is generally sufficiently long for there to be a considerable difference in the height and development of the young crop from place to place during early years, but in most cases it is not sufficient to make these differences permanent.

There are a number of systems coming under this heading and some of them, owing to the long regeneration period, produce permanently uneven-aged woods. Such systems form a transition to the next class in which the woods are all-aged, *i.e.*, the whole range of age classes is present, but they differ from them by having a definite regeneration period, though it is a long one.

(a) *The Group and Irregular Shelterwood Systems.* — In the Group System, groups of young growth already present in the wood, due to openings in the old crop (advance growth), are used as starting points for the regeneration. Such groups, when suitable for the purpose (*i.e.* not too tall and old to merge into the subsequent young reproduction) are looked after by making a succession of regeneration fellings round them so that regeneration spreads outwards from them. In addition, new groups are started in suitable places by making group cuttings in the old wood and are enlarged in the same way. As the groups increase in size and numbers their edges approach each other and finally the intervening portions of the old crop are opened up and regenerated either naturally or artificially. The system was developed for regenerating mixed woods. Generally the groups first formed consist of shade bearers, the conditions being too dark for the more light demanding species. The more rapid opening of the canopy in the later stages permits of the regeneration of the latter, which may be assisted by planting if necessary. In order that there should be no abrupt variations in height and development of the young crop, it is essential that the groups be constantly extended by timely opening of the wood round their margins. Regeneration should always be progressing outwards from the original groups. The object is to obtain an undulating canopy in which the groups rise in irregular, dome-shaped masses without steep sides. The advantages of the system are its flexibility and the minimising of damage to the young growth caused by the felling and removal of the old trees, at least in the

earlier stages. They are felled outwards from the groups and drawn out through the uncut forest. In the later stages, when the groups approach each other, this becomes more and more difficult. Moreover, there is an increasing danger of wind fall in the remnants of the old crop. The flexibility of the system consists in the possibility of varying the size and number of the groups and the extent and nature of the openings in the canopy, whereby conditions for regeneration may be varied to suit particular species.

In the *Irregular Shelterwood Systems* the old wood is more or less uneven-aged and consists of a mixture of light demanding and shade bearing species. Cuts are made, not in the form of group fellings more or less regularly distributed, but by the felling of single trees and small groups all over the area so as to maintain a still rather dark but irregular shelterwood. Groups of young growth spring up freely and the subsequent cuttings determine which groups are to be preserved and utilised. The period of regeneration is generally a long one (40-60 years) and the range of age classes correspondingly great. The procedure is analogous to that of the Selection System, which is described below, except that the range of age classes is not complete as in the latter system.

The advantages of the Irregular Shelterwood System with a long period of cautious opening up of the crop, are the prevention of soil exposure and weed growth, greater security against snow and wind damage due to the uneven canopy, the long period of enhanced increment on the best stems and the elasticity of the system, which gives a free hand to the manager. On the other hand, it favours shade bearers against light demanders. Its chief drawbacks are the scattered nature of the operations which makes them difficult to supervise and control, and may involve serious damage to young growth by the extraction of timber through thickets, etc., besides adding to the expense of exploitation. The system demands a great deal of skill and a thorough knowledge of the forest on the part of the manager, and serious mistakes may be made by new and inexperienced officers.

(b) *The Strip Systems*.—Both in the Clear Felling and the Uniform Systems, operation in large units is the source of many drawbacks. In felling and regenerating large woods the advantages of making the cuts in the form of strips lying side by side in succession has long been recognised. In the Clear Felling System, felling in strips is practised mainly in order to facilitate extraction of the timber away from previous plantings and, by the suitable orientation of the felling front, to expose the uncut margin of the wood as little as possible to danger from wind storms. In a shelterwood strip system, the protection of

the shelter trees from wind by the uncut part of the old stand is an additional advantage, whilst the sheltering effect of the margin of the stand and the shelterwood on adjoining strips is found to hasten the process of regeneration, as it enables the overhead shade to be reduced more quickly.

The strips are taken in hand in succession to that when the earlier ones are in the final felling stage, the others are in the secondary and seed felling stages. Exploitation and regeneration thus advance through the wood in a definite direction. The shelter trees may be felled towards the untouched part of the wood and dragged out through it so as to avoid undue damage to the young growth.

In the Strip Systems, the period of regeneration in a single strip is comparatively short and that of the wood as a whole depends on the width and number of the strips. Generally speaking, the object is to regenerate the wood in a period which is short in comparison with the age of the trees at maturity, so that, although a certain grading in height of the young crop may be evident, the wood becomes practically uniform in later life.

The orientation of the strips and the direction in which the felling and regeneration move through the wood may be influenced by other considerations than exposure to wind storms. On slopes the felled timber has to be drawn out down hill, or at least along the contour, so that, in order to avoid damage to the young crop, regeneration should begin at the top of the slope and progress downwards. The strips may then be formed parallel to the contour. An alternative method, where the above arrangement involves too great a risk of wind fall, is to have the strips running up and down the hill, the timber being drawn into the uncut wood and down to roads running across the slope.

(c) *Combined Systems.*—In the Group System the difficulty of looking after a large number of groups distributed over the area and the danger of wind fall in the shelterwood in the later stages, has led to the development of a system of Combined Strips and Groups, whereby the regeneration of the wood between the groups is carried out in a series of strips and proceeds in a definite direction. In some cases, the groups are formed all over the wood and the strip regeneration advances fairly rapidly through it. Generally, however, it is found better to form the groups only a limited distance in front of the advancing strip fellings, in order that the groups may merge more easily into the strip reproduction. In this way the regeneration of a mixed wood of shade bearers and light demanders may be carried out, the shade bearers being established as groups of advance growth and the light demanders by the strip fellings, which permit of the more rapid opening of the shelterwood which such species require, without danger of wind fall.

(3) **Crop Uneven-aged Throughout.** — In these systems the whole range of age classes is represented in the wood and is produced by a method of exploitation and regeneration which goes on continuously. There is no *regeneration period* as distinct from the rotation and on forests consisting of woods of this kind, fellings of mature timber are made, at least in theory, in all the woods every year. Just as in the other shelterwood systems with a prolonged period of regeneration, the age classes may be mixed by small groups distributed all over the area, or arranged regularly side by side. In the Selection System, fellings are made here and there all over the area where the condition of the crop, old and young, calls for them, in the Border Cutting Systems, cutting is confined to strips taken in hand successively, but so narrow that the progress of regeneration through the wood is slow enough to produce a permanent grading of the crop.

(a) *The Selection System.*—In this system single trees or small groups are selected and cut in all parts of the forest, and in the openings thus created young growth springs up. The aim is to produce and maintain a forest in which all the age (size) classes are mixed together in small units over the whole area. Not only should the age classes be represented, but there should be a proper proportion of stems of each size class. It is therefore not sufficient to confine the fellings to the removal of mature trees. It is also necessary to look after existing groups of young growth by giving them adequate light and to make suitable thinnings and cleanings in the different age classes. A selection felling is therefore a combination of exploitation, shelterwood management, thinning and cleaning. Carried out strictly it is a very difficult and intensive system. It is necessary to determine what is the proper proportion of the different size classes and to calculate and fix the total yield of the forest, which is then provided by cutting in the main in those size classes present in excess.

A true selection forest should have essentially the same character in every part, but actually this is never the case. Owing to differences in the locality, accidents and varying treatment, selection forests vary in stocking from place to place, some parts having a higher proportion of large timber than others.

The Selection System in its highest form has grown out of the ancient practice of cutting here and there in the forest, the trees most suitable for use, *i.e.*, as a rule the largest and finest stems. As no thought was taken for regeneration, this procedure was bound to lead to the destruction of the more accessible forests in which cutting was excessive. Between this method of dealing with the forest, which was purely one of exploitation and not a silvicultural system at all, and the highly intensive Selection System mentioned above, there are all sorts of intermediate forms

which aim at perpetuating the forest in an uneven-aged condition by checking excessive exploitation and fostering regeneration.

The scattered nature of the operations in the true Selection System adds greatly to the difficulty of supervision and the cost of working. It can only be carried out where the forest is comparatively small. In large forests, it is customary to divide the area into a number of blocks, each of which is visited in turn, so that the whole forest is gone over in a period of years equal to the number of blocks. This period is called the *Felling Cycle* and the material cut in a block is the accumulation of that number of years. A large volume is therefore extracted per acre, which not only concentrates the felling operations to some extent, but also opens up the stand more strongly than would otherwise be the case. The Selection System in its strict form is suitable only for shade bearers as the young growth is started in very small groups with considerable side and overhead shade. The heavier cuts possible when the felling cycle is introduced make it easier to raise larger groups and regenerate more light-demanding species. By so doing, however, the characteristics of the Selection System are to some extent lost.

Some of the advantages of the Selection System are:

(1) The forest cover is continuously maintained so that the soil is protected against erosion, land slips, and snow slides and the young growth against sun, frost and wind.

(2) The good crown development of the trees promotes the production of seed and favours regeneration, at least of shade bearers.

(3) Damage by wind and snow is minimised by the uneven-aged constitution of the stand.

(4) The woods are pleasing from an æsthetic point of view as unsightly clearings are avoided.

Its chief disadvantages are:

(1) The scattered nature of the fellings which makes supervision difficult and exploitation costly.

(2) Owing to the diffuse nature of the regeneration, damage to young growth is apt to be considerable.

(3) The timber produced, though it may be of large dimensions, is generally inferior in cleanness of bole and regularity of ring-breadth to that of even-aged stands.

(4) It is difficult to decide on and maintain a proper distribution of age classes.

(5) Where grazing is practised the system is unsuitable as regeneration is not confined to areas from which animals can be excluded.

The merits of the Selection System are the subject of much controversy, especially as regards the volume production as com-

pared with more uniform systems. It is impossible to go into these matters here. There is no disputing its value for forests maintained for protection or æsthetic purposes. Many of the forests of the mountains of Central and Western Europe are managed in this way, but a stringent application of the system with a controlled yield is often absent. In some cases the yield is provided mainly by wind falls and snow breaks and such trees as have to be removed for the benefit of groups of young growth which appear fortuitously in the woods.

In woods managed for æsthetic purposes, the system gives an opportunity of introducing, by planting in small openings, different species of beauty or interest which have the benefit of the side shelter given by neighbouring trees. The size of the openings and the treatment of the surrounding wood can be adjusted to the light and other requirements of the species in question.

(b) *Border Cutting Systems.*—If felling and regeneration are carried out in very narrow strips, the effects of the adjoining stand are evident, not only in protecting the shelter trees from wind, but in modifying the heat, light and moisture conditions in the strip. We have discussed conditions in the margins of woods elsewhere (p. 54) and under the heading *Border Cutting Systems* are included those in which the effects of the margin dominate the conditions for regeneration. One of the effects of the narrowness of the strips is to slow down the progress of regeneration through the wood so that a permanently graded canopy may be produced, and in the most important and fully developed border-cutting system, Wagner's *Plentersaumschlag,* the woods ideally contain the whole series of age gradations arranged in order so that the wood is even-aged in one direction (along the strips) and completely uneven-aged in the other. Wagner claims that woods of this constitution combine the merits of even-aged and uneven-aged woods—ease of supervision, simultaneous ripening, easy exploitation, etc., with protection from dangers, soil conservation, etc.

Wagner's system, as a whole, has been the subject of a great deal of discussion, and whatever its merits, its introduction in practice into forests hitherto worked on other systems, is generally agreed to involve too great a disturbance. On the other hand, Wagner's work, especially his analysis of the conditions in the margins of woods exposed to different points of the compass, and the arguments by which he justified the form and especially the direction of his border fellings, have had a considerable influence on silvicultural practice. (*See:* p. 54.) Though the superiority of the northern margin over others for the success of regeneration has been proved not to hold good everywhere,

Wagner has done great service in calling attention to the great importance of the orientation of the felling front and the advisability of studying its effect on regeneration in all cases.

II. COPPICE SYSTEMS

In contradistinction to the High Forest Systems, which rely directly or indirectly on seed for regeneration, the Coppice Systems are based on the power possessed by many broad-leaved trees, of producing shoots from the stool, stump or bole when cut over. The most important of these systems is *Simple Coppice,* in which the trees are cut over at ground level or near it.

(1) Simple Coppice

As with few exceptions, of which the Redwood (*Sequoia sempervirens*) is an example, conifers do not produce stool shoots, the system is confined to broad-leaved trees, and in practice to a limited number of them. As a rule large stools do not coppice, so that the trees must not be allowed to grow too old. The system is therefore suitable for the production of small and medium sized material, not of large timber, and the *rotation* or period between the cuts rarely exceeds forty years and is generally much less.

The species differ in the number of shoots produced, their rate of growth, the age to which they are produced and the vitality of the stools. The oak, ash, hornbeam, alder, sycamore, lime and hazel coppice freely. The beech and birch are not so vigorous as a rule, and their stools are shorter lived. The oak and hornbeam have a remarkable vitality, the stools remaining productive over many rotations. The alder and sweet chestnut retain the power of coppicing to a greater age than most trees. Most tropical hardwoods coppice well and the coppice system is employed in many parts of India to provide fuel for local inhabitants.

The coppice system is a very old method of treating woods and is interesting as being the first system in which regulation of the yield was practised. The period required to produce material of the size desired is decided upon. The area is divided into as many equal blocks or *coupes* as there are years in this period and these are cut over in turn.

Cleanings and thinnings are generally made in the coppice with the object of removing inferior species and defective shoots and of reducing the number of shoots on the individual stools. This increases the growth of the remaining shoots and also provides material of different sizes. The number of thinnings

depends on the rate of growth and the length of the rotation. When the rotation is short, thinnings are often dispensed with.

Coppice is particularly suited for supplying local demands for fuel, small poles, material for hurdles, etc., but with the increasing use of coal, higher cost of labour and the decline of village industries, coppice is generally less remunerative than it was formerly. In consequence, the area of coppice woods is steadily declining in Britain and in Europe generally.

Owing to its simplicity, the Coppice System does not require a highly trained personnel or elaborate working plans. The annual production of material per unit area differs greatly according to species and rotation. The assortments of material are generally small and their uses limited.

As it is unable to produce large timber, coppice tends to be a subsidiary form of forestry and to disappear as population increases and civilisation develops. Owing to the removal of young material at short intervals, coppice makes considerable demands on the mineral constituents of the soil.

(2) The Coppice Selection System

Instead of the coppice crop being all cleared at one time, selective cuttings are made so as to maintain an uneven-aged coppice crop. This system is little practised, being mainly useful in protection forests in the mountains.

(3) Pollarding

Pollarding consists of cutting the tops off trees with the object of stimulating the production of numerous shoots near the top of the cut stem, and the periodic removal of these at intervals of one or more years. It is hardly a forestry operation and is generally employed in open meadows or along the banks of streams as a method of obtaining willow rods for basket work, fencing, hurdles, etc.

III. COPPICE WITH STANDARDS

Coppice with Standards is a system which combines coppice with high forest. In woods worked under this system, there is a lower storey consisting of coppice, and above it an open wood of standards which, ideally at least, consist of seedling trees and is therefore high forest. The standards form an overwood built up of age classes differing from each other by some multiple of the rotation of the coppice. Thus, with a coppice rotation of 20 years, the standards would consist of trees of 40, 60, 80, etc., years.

In working the system, coupes are formed in exactly the same way as in Simple Coppice. The coppice rotation is decided upon and the area divided into as many annual coupes as there are years in the rotation. In the coupe that is due for felling, the coppice is cut, a certain number of existing standards are reserved for a further rotation, and the remainder felled, and a certain number of new standards of the same age as the coppice are reserved. Finally, blanks caused by the death of stools or the felling of the standards are filled, in order to ensure a further supply of coppice and standards.

The system has the advantage of supplying a variety of produce from a limited area, but the quality of the timber produced is inferior to that of most systems of high forest, the trees being shorter boled and branchy. On the other hand, the coppice is less vigorous than in simple coppice. It is therefore advisable to keep the two systems of production apart, raising timber in high forest and, where small poles and fuel wood are required, to raise them in simple coppice.

The Coppice with Standards system was formerly the most widespread system in England and occupied a very important place in the forestry of France, Germany and Switzerland. In the days when oak timber was in demand for ship building and firewood was easily disposed of, it was very successful in England. With increased use of coal and the substitution of iron for wood in ship building, the demand for the products rapidly declined. As a result many private owners have neglected their woods, which have degenerated in many cases into little more than scrub. The system will, however, probably survive for some time on private estates, partly in the form of games preserves and partly to provide timber, firewood, fencing material, etc., for estate purposes and local consumption. On the Continent, the system is still practised to a large extent on private and communal forests, especially in France. In the State Forests, on the other hand, during the last hundred years, the policy has been to convert former coppice-with-standard forests into high forest for the production of timber, and in France, Germany and Switzerland, at the present time, practically all of them have been so converted or are in process of conversion. In Britain, the Forestry Commission are engaged in converting the former Crown Woods of Tintern from coppice with standards to high forest of hardwoods or conifers, according to the suitability of the particular areas for these crops.

THE SILVICULTURAL TREATMENT OF INDIVIDUAL SPECIES

In dealing with the various factors of the locality and the operations of silviculture reference has been made, by way of

illustration, to the various common species of trees cultivated in Europe. Each species has its own characteristics as regards climatic and soil requirements, and responds in its own way to the various silvicultural operations. It is not proposed to describe the silvicultural treatment of individual species. The requirements of the European species and the suitability of various methods of treatment have been fairly well worked out, but the forester may be faced with the problem of introducing silviculture into a forest in a different climate and with species of whose requirements little or nothing is known. A mere acquaintance with the stereotyped systems of treating European species will not help him much. Unless he has a knowledge of the fundamental matters on which silviculture depends, he is unlikely to tackle the problem with success. It is for the purpose of indicating the nature and importance of these fundamental studies that this book has been written. The silvicultural systems are merely examples of how, in certain circumstances, the continuous production of timber for man's requirements had been achieved with more or less success.

In afforestation, the practical limitation of the process of establishing woods to planning or sowing without shelter, restricts the choice of species to those which can be treated in this way. The choice also depends on the soil and climate and a useful index of these may often be afforded by the nature of the ground vegetation actually occupying the site. A tentative classification of waste-land sites from this point of view has been made in Britain by Mark Anderson. The merits and limitations of this method of site classification will become more evident in the course of time as experience of its application is accumulated.

The choice of a silvicultural system depends on a number of considerations besides the nature of the species, climate and soil. Some systems require a high degree of skill and experience on the part of the management and the personnel and are excluded where these are inadequate. Some are only suitable where working is intensive and there is a good market for material of all sizes. Economic as well as bionomic considerations must be taken into account, and the devising and carrying out of a system which satisfies them as far as possible with the means at his disposal forms the crown of the forester's achievement.

CHAPTER IV

FOREST PROTECTION

INTRODUCTION

The forest is exposed to all sorts of injurious agencies against which it is the duty of the forester to protect it as far as he can, and whose effects he should do his best to minimise. Forest Protection is the oldest branch of Forestry. The first forestry measures were laws to prevent damage to the forest by excessive cutting, uncontrolled grazing, etc.

In the outline of Silviculture in the earlier part of this book constant reference has been made to various injurious and destructive agencies, such as wind, frost, snow, solar heat, fire, insects, weeds, etc., and to the way in which the threat of damage by them limits and modifies silvicultural procedure. Forest Protection is therefore closely bound up with silviculture, but it may also call for special measures of prevention and remedy outside the ordinary silvicultural operations. Owing to the varied nature of the injurious agencies with which Forest Protection has to deal, it must be based upon a number of different branches of study, the chief of which are :

1. Jurisprudence, The Law of Property, Forest Law, etc.
2. Zoology, especially Entomology.
3. Botany, especially Forest Mycology.
4. Climatology and Meteorology.
5. Other branches of Forestry: Silviculture, Utilisation, Forest Management, Forest Policy.

For convenience in keeping together matters connected with the same branch of study and measures of similar nature, it is usual to divide the subject of Forest Protection into sections according to the nature of the agency which produces the damage. The following main sections may be recognised :

(1) Protection against damage by Man.
(2) Protection against damage by Animals,
(3) Protection against damage by Plants,
(4) Protection against adverse climatic influences, and
(5) Protection against other inanimate agencies.

(1) DAMAGE BY MAN

Damage by man is varied in its nature. Certain kinds of damage are due to faulty carrying out of the exploitation opera-

tions and may be reduced by proper marking of the trees to be cut, insistence on the employment of a proper technique and careful supervision. The proper arrangement of the fellings in time and space and the provision of suitable roads or other transport routes are also important means of reducing the damage done to young growth and other growing stock, by felling and transport operations.

Encroachments on the forest, and forest offences, such as injury to growing trees, theft of forest produce, lighting of fires, etc., may be checked by clear demarcation of the forest by suitable boundaries or boundary marks, which should be inspected periodically and renewed when necessary, and by the patrolling of the forest by trustworthy guards and the prompt prosecution of detected offenders. Many forest offences are often due to the poverty of the local inhabitants and a good deal can be done to limit them by selling small lots of the products required on easy terms and by granting permits for the removal of dead wood, fruits, fungi, etc., under suitable safeguards, as well as by giving employment in the forest in the winter when other work is scarce.

The existence of Forest Rights, *e.g.* rights of grazing, wood rights, rights to remove litter, grass, etc., is apt not only to do harm to the forest directly, but also to restrict the power of the owner to enclose woods for regeneration, change the species or system of silviculture, etc. The control and supervision of the right holders adds to the work of the staff both in the forest and in the office, and is apt to lead to disputes and bad feeling. Every effort should be made to get the rights *defined,* as to their nature and amount, the area of the forest to which they apply and the persons holding them. It is sometimes advisable to get rid of the rights if possible, either by buying them from the right holders (*commutation*) or by setting apart a portion of the forest as a common for their exercise and handing it over as a property to the body of right holders, in return for the freeing of the remaining part of the forest from all rights (*cantonment*).

Protection Against Fire

Though occasionally forest fires may originate from natural causes (*e.g.* lightning), in the vast majority of cases they are due to human action, either within or without the forest. It is therefore convenient to deal with fire protection under Damage by Man. Some of the most frequent causes of forest fires are carelessness or recklessness — throwing down lighted matches or cigarettes, lack of proper attention to fires lighted for camping or burning forest refuse, heather burning, etc. A great many fires are caused by sparks from railway engines. Occasionally they arise through incendiarism.

Forest fires are due, in the first place, to the inflammability of the ground cover—dry grass, leaf or needle litter, twigs, etc. They are most frequent, therefore, in the late spring, when there is much withered material, but the young succulent growth has not yet developed. They are also frequent in dry summers. Young coniferous woods are most endangered as the ground cover of needles and twigs is very inflammable and the flames easily mount up into the dead, lower branches and reach the crowns. Young plantations with unclosed canopy and much weed growth are also very liable to damage by fire. Old woods, also, with an open canopy and heavy ground vegetation are apt to suffer, the trees being injured or killed by scorching of the bark. Woods in the pole forest stage with a dense canopy are little endangered. The arrangement of woods so as to avoid large contiguous areas of conifers in the dangerous stage is an important means of limiting the spread of forest fires.

The most important types of forest fires are *Surface* or *Ground Fires* and *Crown Fires*. The first are the most common and consist of the burning of leaves, twigs, grass and other ground vegetation. Crown fires, which burn the leaves and branches of trees, always originate as ground fires, which, having ample fuel and space to develop into a fierce conflagration, mount up into the crowns of the trees. Occasionally peaty, moorland soils may become ignited and burn slowly and persistently. These *deep soil fires* can be limited by surrounding the burning area by ditches cut down to the mineral soil.

Measures of protection against forest fires are (1) *preventive measures* directed towards preventing the outbreak of fires in the forest, the spreading into the forest of fires originating outside and the limiting of the extent of fires actually occurring in the forest; (2) *combative measures* for extinguishing fires, and (3) *remedial measures* for minimising the evil effects of fires and restoring the productivity of the forest.

Preventive Measures.—As conifers are much more subject to fires than broad-leaved trees, mixing of the latter in coniferous crops and making belts of broad-leaved trees at intervals, especially along rides, roads and railways, reduce the fire hazard. Regulations should be made prohibiting the lighting of fires, smoking, etc., during dangerous periods and the forest should be patrolled by *fire wardens* or watchmen to see that the regulations are obeyed and to deal with incipient outbreaks. Since all forest fires depend upon the inflammability of the ground cover, fires originating outside the forest (burning gorse, heather, herbage, etc.) may be prevented from spreading into the forest by the provision of a belt of ground along the margin of the forest, free from inflammable material, sufficiently wide to prevent sparks and

burning fragments being blown across. A system of intersecting paths or rides, commonly eighteen to thirty feet wide, should be arranged through the forest, so as to aid in confining a fire to one section. Such lines form the best protection against the spread of a fire and are a great help also in extinguishing it.

Combative Measures.—The first essential in fire fighting is promptness in getting the personnel and appliances to the spot. To insure this, arrangements must be made for timely notice of an outbreak to reach the responsible authority. A good system of patrols is useful and, in large forests, watch towers may be erected from which all parts of the forest can be overlooked and notice of the presence and position of a fire can be communicated to the central control station by telephone or signal. (*Plate* II B *facing p.* 96.) Arrangements should be made for the summoning of the fire-fighting force and, where necessary, for its transport to the spot. All forest employees and concessionaires should be bound to turn out and help in combating fires, and in some countries the local inhabitants are legally obliged to assist. Every man should be instructed beforehand as to the measures to be adopted, the person under whose orders he is to place himself and the tools or appliances he should bring with him.

A ground fire should be attacked from both sides simultaneously by beating or rather sweeping inwards with green branches or brooms so that it is gradually narrowed into a wedge shape, headed off and extinguished. Earth hastily thrown over any part where the fire threatens to cross the protection lines is very efficacious.

A crown fire cannot be attacked directly; it can only be extinguished by depriving it of fuel. If time allows, a strip of trees along a road or fire line may be felled towards the advancing fire and the crowns of the trees cut and removed beyond the reach of sparks. In extreme cases, it is necessary to counterfire. Counterfiring consists of burning woods along one of the defence lines in front of the fire. The counterfire spreads towards the main fire, at first slowly and then more rapidly because there is a draught towards the centre of conflagration. Finally, it mounts up into the crowns and the two fires meet and are extinguished owing to want of fuel.

After a fire is apparently extinguished, watch should be maintained until all chance of a renewed outbreak is past.

Remedial Measures.—Young coniferous woods which have suffered seriously should be cleared and planted. Dead and dying conifers, such as are left after a fire, readily become breeding places for insect pests, especially bark beetles. With broad-leaved trees there is not the same need for haste and they often coppice if cut over at the base.

(2) DAMAGE BY ANIMALS

The chief classes of animals which cause damage in the forest are: (1) Domestic Grazing Animals, (2) Game, (3) Small Rodents, (4) Birds, (5) Insects.

Domestic Grazing Animals.—The various domestic grazing animals damage the forest by nibbling buds and shoots, trampling upon seedlings and young growth, consolidating the soil in places, loosening it on steep slopes, treading down the sides of ditches, etc. Of the European domestic animals, the *goat* is the most destructive, as it feeds on woody plants in preference to grass or other herbs and is very active. Where goats are numerous, natural regeneration is impossible and the destruction of the forest in the course of time is inevitable. *Sheep* come next to goats in point of harmfulness. *Cattle* and *horses* prefer grass to woody plants, but also do damage by browsing and treading. *Swine* are generally beneficial on the whole, as, though they devour quantities of forest fruits and uproot seedlings, they also destroy a number of caterpillars, pupæ and mice and cultivate the soil by their rooting. If possible, goats and sheep should be totally excluded from the forest. Cattle and horses should only be admitted to woods in which the foliage is out of their reach and when there is ample legitimate food for them. Adequate supervision by herdsmen is necessary.

Game Animals. — In many forests and woodlands, the maintenance of a head of game is considered to be one of the objects of management. The chief game animals are deer of various kinds, rabbits and hares, all of which do more or less damage to the forest. The relative importance attached to timber production and sport will determine the extent to which productive efficiency is to be sacrificed for the sake of the animals.

The *rabbit* is the most harmful of all animals maintained for sport. It bites and gnaws the bark of woody plants, nibbles young shoots and does a certain amount of harm by burrowing. Rabbits are very destructive of young growth and may prevent natural regeneration entirely and even a few of them will ruin a young plantation in a short time. So great is the destruction wrought by rabbits that serious forestry and the presence of a large number of rabbits are quite incompatible. Fencing with wire netting fences may be some protection to young plantings, but not only does it add greatly to the cost of establishment, but is apt to be ineffective, especially in snow, and requires constant supervision. Owing to its small sporting value and its great destructiveness, the rabbit should be treated as vermin and everything possible done to exterminate it. Its enemies, such as weasels, stoats, foxes, etc., should be encouraged. Shooting and trapping, at all seasons of the year, driving by ferrets, smoking

out of its burrows by sulphur dioxide fumes, etc., are means employed to eradicate it. The *hare* is less destructive than the rabbit, but does damage of similar nature. It attacks forest plants only in winter, especially when there is snow on the ground. Fencing of forest nurseries and young plantings and keeping the numbers of the animals within bounds by shooting, etc., mitigate the amount of damage.

The various species of *deer* do damage of various kinds in the forest such as nibbling buds, shoots and leaves, devouring forest fruits, stripping the bark from young poles, trampling down seedlings. Among the measures which are adopted to minimise the damage are fencing out of young plantations, protection of specially valuable trees by wire netting or other guards or by smearing them with bad smelling substances. One most important measure is the provision of nourishment for the animals so that they will not be driven by hunger to attack trees and young growth. The growing of mast- and fruit-producing trees in suitable places, cultivation of fodder crops in the forest of types suitable for the particular species of game, encouragement of the growth of grass in the forest, suppression of grass cutting and pasture and the feeding of the deer in winter when there is much snow on the ground are all useful measures. Finally, the head of game should be reduced if necessary to a restricted number which the forest can bear.

The Smaller Rodents. — The principal animals of this class are squirrels, mice and voles. The squirrel does damage by eating forest fruits and flowers, nibbling through twigs and stripping the bark from stems and branches in the crowns of the trees. The chief method of dealing with them is shooting. Trained dogs may be useful in finding the animals. Their nests may be destroyed in spring. These are found generally in young thickets and are easily seen and reached. Mice and voles cause injury by gnawing the bark and sapwood of young trees, devouring seeds and fruits and injuring small plants by burrowing. There are several species of mice and voles found in European forests. Some breed and feed in fields during the summer and invade the forest during the winter. Trap ditches with vertical sides may be made round seed beds, young plantations, acorn stores, etc. Trapping, and poisoning by means of grain or bread crumbs impregnated with strychnine, etc., are methods of direct attack on the animals, which may be carried out in the fields which they are infesting. The enemies of mice and voles should be encouraged and grass and low undergrowth which shelter the animals should be cut before winter. In seed beds, seed should be given a coating of red lead, by stirring up one part of red lead with ten parts by weight of seed, with a little water sprinkled in to make it adhere.

Birds. — Generally speaking, the injury done by birds in the forest is outweighed by their usefulness in destroying injurious insects. There are, however, a certain number of species which do considerable direct harm to the forest, chiefly by devouring seeds. Among such species in Europe are: the Capercaillie (*Tetrao urogallus*), which devours the buds of pines, wild pigeons and jays, together with small birds of the finch family. A number of predatory birds do harm by destroying useful birds and may be said to be indirectly injurious. Some birds are on the border line, such as the woodpeckers and also some of the *raptores,* which besides devouring useful birds also destroy many mice and voles. Sowings may be protected by placing coloured strings across them, by wire netting covers, by dressing the seed with red lead as for mice and voles. Scarecrows and paper feathers on strings are sometimes useful, at any rate for a limited time until the birds get used to them. Firing off blank cartridges to scare birds away from seed beds and sowings may also be employed. Shooting of pigeons and jays should be done systematically.

Generally, the forester should familiarise himself with the appearance and feeding habits of the birds and other animals to be found in his forest and learn to distinguish the harmful from the harmless or useful. In the main, the smaller the animal the more difficult it is to control. The larger animals, though individually doing more damage, are, owing to their smaller numbers and the ease with which they can be fenced out, scared away or hunted, generally speaking, far less serious enemies of the forest than the small ones, such as mice and voles, which, owing to their great powers of multiplication and their concealed mode of life, are much more difficult to deal with.

Insects — Insects, as a class, are so destructive in the forest, and their small size and obscure mode of life make them so much less easily observed than the destructive mammals and birds, that considerable special study has been devoted to them in order to diagnose the injury they do and discover means of limiting and combating their attacks.

Two of the chief characteristics of insects are their complicated life history and their immense power of multiplication under favourable circumstances. Forest Entomology is the study of insects, both useful and harmful, which are important to the forester. The forest entomologist, from his knowledge of the habits and life conditions of an injurious insect species, may suggest means of control which it is the duty of the forester to carry out if they are feasible, having regard to the physical and economic limitations under which he must work.

Most important forest insect pests attack only a certain kind of plant, or at least a certain group, *e.g.* only broad-leaved trees

or only conifers. The conifers generally suffer more from insect attack than broad-leaved trees, partly because they have more numerous and more injurious insect enemies, but partly also because they have a smaller power of repairing injuries and replacing lost organs and tissues than the broad-leaved trees.

Almost every part of a plant or tree may be attacked by some species of insect and the seriousness of the damage depends not only on the amount of destruction wrought, but on the effect produced on the future development of the tree. The destruction of roots of young plants by cockchafer grubs, the rind of young conifers by the Pine-weevil, the cambium of stems by certain bark beetles and the stems of seedlings by surface caterpillars generally leads to the death of the attacked plant because it interferes with the physiological processes of nutrition and growth. When the twigs and buds are attacked, malformations, double leaders in conifers, etc., as well as checking of growth by the reduction of the assimilating organs may result without involving the death of the plant. Leaf and needle eating insects are less important unless they are very numerous. Broad-leaved trees can stand even complete defoliation without succumbing, though there is naturally a loss of increment, and in certain cases, abnormal formation of the wood. Conifers are more sensitive and massed attacks by defoliating insects such as the Nun Moth, Pine Beauty, etc., are very serious. Certain insects confine their attacks to the wood of the stems and branches. Generally speaking, they are not harmful to the tree as a growing organism, but they may reduce the value of the timber. Such insects are said to be *technically harmful,* whilst those previously mentioned are *physiologically harmful.*

Certain insects are capable of attacking healthy, flourishing plants. Among them are root, rind, shoot, leaf, flower and fruit infesting species. They are said to be *Primary Insect Pests.* Others, including most of the bark, cambium and bast inhabiting species, only attack trees already unhealthy or enfeebled from some other cause (defoliation, fungal attack, frost, fire, drought, smoke, etc.) or felled material. These are termed *Secondary Insect Pests.* There are also some which are normally secondary pests, which, when they are very numerous and suitable (unhealthy) breeding material is absent, may develop into primary pests and attack healthy trees. Finally, there are species which in one stage of their development are secondary pests and in another stage attack healthy plants. An example of this is the Pine Weevil, which, in the larval stage, is a secondary feeder, but as a perfect beetle makes a primary attack on young conifers.

Insects are individually small and if only a few of them are present, the damage they do is insignificant. In the balance of

nature, their numbers are kept within bounds by certain factors which work against them. Among these are: adverse weather conditions, scarcity of suitable nourishment, or suitable breeding places, the presence of enemies of the animal world (birds, mammals, predatory and parasitic insects) and disease-producing organisms. When one or more of these barriers to their multiplication are weakened or removed, they may develop into a veritable catastrophe for the forest. In artificially worked forests, the balance of nature is apt to be upset in various ways and insect plagues occur in consequence.

The measure of protection against insects may be divided into (a) Preventive and (b) Control Measures.

Preventive Measures.—The aim of these is to prevent the undue multiplication of insects and to keep them from attacking the forest. They include (1) silvicultural measures and (2) protection and encouragement of their enemies.

(1) Strong, healthy plants are less liable to insect attack and better able to resist it than feebler ones. The choice of suitable species and proper methods of treatment, careful maintenance of the soil fertility by retention of litter, management of the canopy, drainage, underplanting of light demanders by shade bearers, etc., promote the vigour of the trees and reduce the damage done by insects. The avoidance of large, pure woods and the establishment of suitable mixtures where possible, especially the mixing of broad-leaved trees with conifers, which are specially menaced by insect pests, are very advantageous.

The forest should be kept as free as possible from dying and dead material which provides breeding places for a large number of injurious insect species, felled logs should be promptly removed from the forest or at least barked, large useless branchwood should be burnt. Measures of protection against frost, fire, wind and snow are also indirectly measures of prevention against many insect pests, as they reduce the amount of such material.

Large clearings which lead to extensive, even-aged woods should be avoided. The arrangement of small felling areas in suitable cutting series, so as to avoid felling on adjoining areas at short intervals, is an important protective measure against certain insects (Pine Weevils) which breed in the stumps of felled trees and afterwards attack young plants. Some insects prefer large clearings for egg laying (Cockchafers).

Systematic observation and noting of the presence of colonies from which insect plagues may spread is an important measure. The forester and the personnel generally should be familiar with the outward signs of a threatening insect plague. Among these are: the abnormal assembly in certain places of

insect eating birds, the presence of bitten leaves or needles, excrement, filaments or webs on twigs, outflows of resin, discoloration or casting of the rind, bore dust, bore holes in stems, appearance of ichneumons in large numbers, etc. Rewards should be given to the personnel for the detection of very dangerous insects and for carrying out protective measures.

The animal enemies of insects include mammals, birds and predatory and parasitic insects. Bats, moles, shrews, hedgehogs, pole cats, weasels and badgers are European species which destroy many insects and should be protected. Insect eating birds should be preserved as far as possible by destroying their enemies, *e.g.* cats, jays, magpies, ravens, shrikes, and species of hawks, and their multiplication promoted, by preserving a few hollow trees in the forest and providing boxes for nest building on trees. Cover should be provided by shrubs and bushes in sheltered places, especially along brooks and near springs. Birds should be fed when deep snow is on the ground, suet or chopped meat being suitable for insectivorous birds.

Certain predatory insects belonging to various natural orders are useful in keeping down insect pests. Ground beetles, tiger beetles, ladybirds and a number of other beetles, ants, wasps, dragonflies and hoverflies feed on other insects. The *Ichneumons* and *Tachina* flies lay their eggs in or on the bodies of other insects, either in the egg, larval, pupal or imaginal stages, and feed parasitically on their hosts, ultimately causing their death. They are the most important animal enemies of insects and play a great part in keeping the insect population in check. Their powers of multiplication are of the same order as those of their host insects, so that, though they may at times fail to prevent an outbreak of an insect pest, they contribute greatly to bringing it to an end. Useful insects are protected by not destroying them when caught in trap trenches, etc. Spiders and millipedes are also enemies of insects.

Control Measures.—Control measures against insects may be divided into (1) technical measures which by mechanical or chemical means seek to destroy the insects directly, and (2) biological control measures, which call in the help of the natural enemies of the insects, whether insect eating animals, predatory or parasitic insects, or animal or vegetable agents which produce diseases. In forestry technical measures of control are less important than in agriculture and horticulture. Apart from the collection of insects in certain cases, use of trap trees, grease bands on stems and, perhaps, in the future, dusting with poisons by means of aeroplanes—silvicultural preventive measures are far more important.

Among technical control measures the collection and

destruction of eggs, larvæ, pupæ and perfect insects may be carried out to a limited extent in Forestry. At which stage in its life history the application of such methods is easiest depends on the mode of life of the particular insect. From a practical point of view it is necessary that control measures should be applied at a time when suitable labour is available. Collection of eggs is only feasible when they are laid in clusters in a position easily seen and reached. Larvæ may be picked off the plants or the soil, or, after shaking the attacked trees, from sheets placed on the ground to catch them. Certain larvæ feed in companies which can be crushed with the gloved hands when within reach. The grubs of cockchafers and other ground insects may be dug up in nurseries and the pupæ of some insects are found in the litter or low down in crevices on the bark of trees. The collection of perfect insects may be done by picking them off the plants and the ground, by shaking them from the trees like larvæ. Many beetles can be caught in traps (bark, billet, brushwood traps), to which the insects are attracted, or by trap trenches into which they fall.

Grease bands round the stems of trees which prevent caterpillars from climbing up into the crowns have been employed with success in cases where the larvæ hibernate in the litter.

Insecticides, of which a very large number are to be had in the market, may be divided into two classes, *i.e. contact poisons*, which kill the insect or larva by stopping up its breathing apparatus or paralysing its nervous system and *food poisons* which adhere to leaves, etc., and are swallowed by the insect. Food poisons are effective with insects or larvæ which have biting jaws, but not for those, like the plant lice and scale insects, whose long sucking apparatus is sunk in the tissues of the host plant.

Until recently it was only possible to distribute insecticides effectively in liquid form by means of a portable or movable spraying apparatus. Owing to the cost alone, chemical control methods could never play so important a part in forestry as in agriculture or horticulture. Insecticidal liquids could only be applied in nurseries and young thickets and plantations, whereas with the more important forest insect pests the method failed completely because it was impossible to spray woods from above, and, moreover, the provision of the necessary water for dissolving the insecticide was often very difficult.

In order to get over these difficulties, firstly of distributing the poison from above, and, secondly, of providing water, experiments have been made recently in the use of aeroplanes for combating insect pests. The insecticide is distributed in the form of a fine dust, which settles in a cloud on the foliage of the

trees. The great advantage of the method is the extraordinary saving of the time and personnel it affords. The results so far indicate that under suitable conditions it may be very successful with certain important forest insect pests. Among the matters which influence the success of the method are the weather conditions, the stage of development of the caterpillars and their nature and feeding habits. Improvements in the equipment (distributing apparatus, aircraft, form of poison) and the technique are being made. The first experiments were made with food poisons (lead arsenate, etc.), but contact poisons are now also being tried. So far the method is the only one yet found of attacking directly a serious plague of leaf-eating caterpillars in the forest. On the other hand, the question arises as to whether the distribution of poisons broadcast in this way may not cause injury, not only to bees and grazing animals, but also to the general insect population whereby the biotic equilibrium may be upset and other checks on the multiplication of insect pests weakened.

Chemical control of soil inhabiting insects is practised to a limited extent in forest nurseries. The introduction of insecticidal liquids, especially carbon disulphide, in small quantities into soil, infested with cockchafer grubs or wireworms, is an example, but the method is of limited application.

Biological Control Measures by which the means provided by nature are employed are more suitable for the conditions of the forest than technical measures. We have already mentioned the advisability of protecting and encouraging the various wild animals which act against insects. The admission of domestic swine and fowls into the woods, infested with certain insects which hibernate or pupate into the litter has also been tried with varying results.

With regard to the predatory and parasitic insects, which are even more important, attempts to introduce and breed them in case of insect calamities have so far met with little success. The same is true of experiments in infecting caterpillars with the diseases which, in nature, play such an important part in bringing insect plagues to an end. Nevertheless, with advancing knowledge of the habits and life conditions of insects and their parasites, it is possible that some progress in these directions may be made. In the meantime the silvicultural *preventive measures* are the most important means of limiting the damage done by insects in the forest.

It is not proposed to give an account of individual insect pests in this book. Sufficient has been said to show that the forester should have some knowledge of insects in general and the appearance, habits and life histories of the more important forest insects, both useful and harmful, in his district.

(3) DAMAGE BY PLANTS

The chief kinds of plants which are injurious to forests are weeds which cover the soil, climbers and parasitic green plants and fungi which attack trees or young forest plants.

Forest Weeds

Forest weeds may be defined as plants which, growing singly or in masses, injure trees directly or indirectly or interfere with forestry operations. This definition may be deemed to include trees of inferior species which prejudice the growth of the main species in the forest. It is necessary to remove these in cleanings and thinnings, and this has already been dealt with under Silviculture.

The most troublesome forest weeds are, as a rule, woody plants of more or less rapid height growth, herbaceous plants which spread by means of underground stems, and coarse grasses.

The injury done to woods by the presence of weeds depends on the nature of the weeds and the conditions under which they develop. The matted roots of certain weeds interfere with regeneration and increase the cost of soil preparation. Weeds may deprive young forest plants of moisture, light, soil nutrients and heat. Some species smother and constrict plants by climbing up them and others, such as coarse grass and bracken, may be crushed down on them by snow. Certain plants form acid or dry humus with their debris, which is unfavourable to forest plants, *e.g.* heather, reeds, etc. Coarse grass may prevent light showers reaching the soil and transpire large quantities of water and so increase danger of drought, besides giving shelter to mice and voles. Some weeds, especially heather, increase the danger of forest fires. Parasitic phanerogams deprive trees of sap (*e.g.* mistletoe and dodder), and epiphytes such as lichens exclude air from stems by blocking up lenticels. Certain weeds act as hosts for fungi, which in another stage of their life attack forest trees.

Preventive Measures against Weeds.—Most of the common and troublesome weeds are light demanders or partial shade bearers. They make their appearance when the crown canopy of the forest is opened up naturally or artificially and especially on clearings. The maintenance of the density of the forest is therefore an important preventive measure. On soils liable to become weedy, regeneration fellings should be made with caution, all blanks in the reproduction should be quickly filled with strong transplants, long rotations should be avoided, as old woods tend to open up. Woods of light demanding species

(oak, larch, pine) should be underplanted at the right time with shade bearers. Clearing should be promptly planted up with strong transplants, planted closely. Forest nurseries should not be too near fields and seed beds and nursery lines should be carefully weeded before the weeds seed.

Remedial Measures.—The nature of the remedial measures depends on the habit of the weeds. They must also be as economical as possible. It is possible to eradicate or at least practically destroy weeds if sufficient time and labour are devoted to the purpose, but it is the object of forest protection to employ methods which will reduce their harmfulness with a minimum expenditure of money.

In preparing an area of ground for afforestation, methods are feasible which it is not possible to adopt when a young forest crop is already present. Thus a heavy growth of grass or herbage may be grazed by cattle, heather or gorse can be burnt, bracken may be mowed. Weeds may be pulled up or cut down, always before the blossoming period. Raspberries and brambles are not cut because they will send out new shoots, but are beaten down. Woody climbing plants should be cut repeatedly below ground until no new shoots appear. The stems of woody twiners should be unwound. Grass and heather may be ploughed up or grubbed up completely or in strips or patches.

Plants which may act as weeds in some circumstances may act beneficially in others. A growth of high weeds, if not too dense, may form a useful shelter to tender plants against frost and dry winds. Brambles, holly and other prickly growth may protect young plants against the browsing of game and other animals. The nature of the ground vegetation may form a useful indicator of the soil and lighting conditions in regeneration and of the suitability of the locality for various forest crops (see p. 111).

Protection Against Fungi and Bacteria

Fungi and bacteria are plants which are without chlorophyl and are consequently unable to make use of the carbon contained in the carbon dioxide of the air. They obtain their supplies of this essential element from organic material which they attack and digest. Some of them make use only of dead material, whilst others are capable of attacking living organisms. The former are called *saprophytes* and the latter *parasites*.

The bacteria are very minute, single celled organisms which multiply by division. Some of them are the causes of serious diseases in man and animals, but as a class they are of little importance in causing diseases in the forest, compared with the

fungi. On the other hand, they play a great part in the breaking down of plant debris, as has already been mentioned when discussing the formation of humus in the forest (p. 53).

The fungi, besides useful and innocuous species, also include numerous harmful ones, which are injurious to living plants, including trees, or to timber and are therefore of importance to the forester.

The branch of Botany which deals with fungi is called Mycology. The forester should be acquainted with the general morphology and physiology of fungi and the outward appearance of the commoner fungoid diseases and injuries. The working out of the life history, mode of attack, conditions of infection of a species of fungus, and the determination of whether a fungus which is present is the cause or only an accompaniment of the injury, are often very difficult and call for the skill of the expert mycologist. In general, it must be admitted that the forester has even less control over fungoid diseases than over insect pests.

Every fungus consists of a *mycelium* and a *sporophore*. The former takes in the nourishment and performs the vegetative functions, whilst the latter bears the organs of reproduction, whether sexual or asexual. The mycelium consists of a mass of fine tubes or filaments which branch repeatedly. These filaments are called *hyphæ,* and, according to the species of fungus, they may penetrate the cells of the host plant or they may go between the cells. In the latter case they send out branches into the cells through which they absorb their contents or attack and dissolve their walls. As a rule the mycelium of the fungus is concealed within the host plant, but the sporophore is generally situated on the surface so that the spores may be scattered abroad. Some fungi, however, develop their mycelia on the outside of the host—*e.g.* mildews and some of the root infesting species in the soil. Others, by developing a special type of mycelium with hyphæ with thick walls, are able to traverse spaces in which moisture may at time be deficient.

The sporophores of fungi vary in form and structure and it is by them that the mycologist identifies and classifies the fungi.

The fungi which cause damage or disease to woody plants nourish themselves either on dead or living plant tissues. Those which can live only on dead parts of plants are called *obligate saprophytes,* whilst those which attack only living tissues are *obligate parasites.* If a fungus can change its saprophytic mode of life and become parasitic it is called a *facultative fungus.* Facultative fungi attack, in the main, plants which, through some cause (non-parasitic or animal parasitic) are already enfeebled or injured. The life history of some species of fungi is completed on a single host, but certain groups of fungi attack

different hosts at different stages in their life cycle. This is the case with many " rust " fungi.

Spreading of Fungi. — The infection of a plant by a fungus is generally brought about by spores, but sometimes, with root parasites, by mycelium growing out into the soil from the diseased plant. The spores are minute, unicellular organisms, which are much more resistant to drought and cold than the delicate mycelium. They are mainly transported by wind or rain and to a much less extent by animals. When the spore germinates on the host plant, the germ tube which develops from it penetrates into the tissues by boring through the epidermis or by using one of the stomata or lenticels as an opening. In the case of the so-called wound parasites, the germ tube is unable to penetrate an uninjured epidermis. Infection by these fungi is only possible when it has access to a suitable tissue exposed by a wound.

Experience has shown that the danger of infection for individual plants and the spread of a fungoid disease are by no means the same everywhere and in all circumstances, but change according to age, stage of development and health of the attacked plant as well as the time and place of the attack. For a plant to become diseased there must be present a condition of the plant which makes it susceptible to attack and the external agent which brings about the disease such as the fungal spore or mycelium. The " predisposition " of a plant to the attack of a particular fungus may proceed quite naturally from its normal development, *e.g.* condition of youth, stage of vegetation or inherent character. In such cases, the predisposition is said to be " natural." If the predisposition depends on outward conditions such as unfavourable weather (excessive wetness, drought, frost), faulty nutrition (excess or deficit of various nutrients), wet soil, mechanical injury, insect attack, damage by smoke or fumes, etc., it is termed an accidental or abnormal predisposition. Since a great many of the important fungi are secondary pests, *i.e.* they only attack plants already diseased, enfeebled or injured in some way, the most fruitful methods of protection are directed to removing or minimising the conditions which make plants susceptible of infection and so reducing their predisposition. The external climatic conditions which promote the outbreak and spread of fungoid diseases are dampness, stagnant air and warmth.

Damage done by Fungi. — As the fungus extracts nourishment from the host plant, it naturally interferes with its normal physiological functions. This interference results in all sorts of pathological changes in individual cells, tissues and organs, which may lead to the death of the attacked part or

even of the whole plant. Where the fungus prevents the supply of water by damaging the basal part of an organ or the roots of the plant, rapid death of the organ or the plant is bound to follow. Many fungi, on the other hand, which attack wood, rind or leaves, do not bring about the immediate death of the plant, but by breaking down the wood, cause reduction in value or by causing drying and death of parts of the rind or by defoliation bring about loss of increment. In other cases, the fungus does not so much destroy the tissues it pervades as deform them, apparently as the result of stimuli emanating from the mycelium. Accelerated growth then leads to enlargement and multiplication of cells and to abnormal growths (cankers), multiplication of shoots (witch's brooms), swellings, twistings and bendings; in short to all sorts of malformations, which again result in loss of value of material, reduction in seed production or other injuries. Such effects are generally the result of the action of obligate parasites such as rust fungi.

Though the damage done by fungoid epidemics does not appear to be so catastrophic as that sometimes resulting from the multiplication of insects, nevertheless widespread damage is done by them.

The most serious forest fungoid pests are (1) those causing diseases in seedlings and young plants, (2) root parasites and (3) timber destroyers. The first class often cause great losses in nurseries and young regeneration and plantations. Their attacks are sometimes of an epidemic character and in some cases are so common that the forester carries out protective measures as a matter of course. An example of such a fungoid pest is the Needle Shedding Fungus of pines (*Hysterium pinastri*) against which spraying of pine seedlings in nurseries and plantations with a fungicide is a normal process in large regions on the continent of Europe. The root attacking fungi are troublesome owing to the great danger of infection from their spores and mycelia concealed in the soil, the small resistance of the delicate rootlets and especially owing to the importance of the roots in the life of the tree. The timber-destroying fungi can very seriously reduce the proportion of useful material and so lead to great financial loss.

Though there are a very large number of fungi occurring on forest trees, only a few of them are of great practical importance owing to their general distribution and their persistent and intensive attack. As in the case of insects, the conifers are more often and more seriously attacked than broad-leaved trees.

Protective Measures.— In protection against fungi, preventive measures are more important than control measures. As with few exceptions, the fungus permeates the tissues of its

host, it is impossible, as a rule, to destroy the fungus without, at the same time, destroying the plant or at least part of it. This is not always practicable, especially on a large scale. More important, however, is the circumstance that in many cases of plant disease, the fungus is not the primary cause. Only where some other injurious influence has prepared the ground does the fungus find conditions that suit it. It is therefore best to remove the condition of susceptibility and its causes as far as possible.

Preventive Measures.—The production of sound, resistant individual plants is the foundation of protection against fungi. This implies not only the practice of sound silviculture, but also the selection of a variety or race of trees suited to the locality. Just as the individuals of a species vary in their resistance to one and the same species of fungus, so also do different varieties and races. The protection of plants from injury by such agencies as frost, wind, snow, fire, insects, waterlogging of the soil, and from wounding by grazing, or by felling or logging operations, all of which increase susceptibility to fungoid diseases, is also an important preventive measure.

Infection may be checked by such measures as isolating diseased plants by trenches (root fungi), collecting and destroying sporophores (not very practicable as a few sporophores overlooked will produce millions of spores), closing wounds by tar, carbolineum, etc., destruction of weeds that act as intermediate hosts (rust fungi), spraying or dusting with fungicides to destroy spores alighting on the plants.

Control Measures.—The chief control measures are (1) the destruction of the attacked plant or the removal and destruction of the attacked part. This is, as a rule, only practicable with small plants which can be pulled up and burnt. The removal and destruction of branches, etc., from older trees is generally confined to valuable ornamental trees; (2) Spraying or dusting the diseased plant with chemical fungicides. In forestry practically the only fungicides employed are copper-containing compounds and preparations of sulphur, which are applied to young plants, the former being effective against the needle shedding fungus of pines and the latter against oak mildew and the needle shedding disease of larch (*Meris laricis*).

(4) ADVERSE CLIMATIC INFLUENCES

Something has already been said in the Chapter on the Foundations of Silviculture about the relations of trees and the forest to the various factors which go to make up the climate and how trees are able to adapt themselves to a certain range of variations in these factors. It was also shown that the forest

itself modified the climate within it, moderating the extremes of heat and cold, regulating the soil moisture and checking the force of the wind, and thereby influencing the growth and well-being of the trees and young growth. The chief climatic phenomena which are liable to cause injury to the forest in certain conditions are: frost, heat, drought, wind and precipitations (rain, hail, snow, hoar-frost, ice). These phenomena are by no means always injurious. In ordinary circumstances they are innocuous or even beneficial, but their evil effects become evident when their intensity or time of occurrence is abnormal or the conditions of the locality, or the crop or the stage of development of the plants is unfavourable so that the power of resistance of the latter is reduced or permanently destroyed.

As the nature of the weather is outside the control of the forester, the measures of protection he can adopt consist in producing conditions within the forest which enable it to offer the greatest resistance possible to the adverse effects of these phenomena.

Protection Against Frost

The damage done by frost takes three chief forms :—

(1) The freezing of young plants and the tender parts of trees.
(2) The production of Frost Cracks in stems.
(3) Frost lift of young seedlings.

(1) *Freezing of Young Plants and Plant Parts.*—The damage done consists of the killing of the cells of living tissues either of the whole or part of the plant. Parts of the plant which are growing or are about to grow or have just ceased growing are more sensitive than those which are in a dormant state, and when the frost occurs in the depth of winter it is much less liable to do damage than one of equal or even considerably smaller intensity which occurs in the growing season. Something has already been said of the change in sensitiveness to frost which occurs in plants in the course of the year (*See:* p. 21). The amount of injury done by frost to forest plants depends on numerous factors: species, stage of development, part of the tree, power of healing as well as the factors which influence the actual intensity of the frost such as density of crop, topography, soil cover, weather, etc.

Assuming that the trees are growing in their natural habitat and in a suitable locality, broad-leaved species are generally more sensitive to frost than conifers. If the trees are growing outside their natural habitat, their behaviour as regards frost depends very much on whether the original habitat of the species is warmer or colder than that into which they have been introduced. Species from warmer regions, introduced into a cooler climate,

suffer through early and winter frosts more than do those from a more northerly or elevated region. The lower summer temperature delays the ripening of their shoots, which thus remain sensitive to autumn frosts. On the other hand, owing to the cold weather in spring, they do not start their growth till late and so sometimes escape late frosts altogether. The opposite is the case with species from more northerly or more elevated localities. In their case, danger from late frosts is increased, because they react to the warmer spring temperatures by starting growth early. As a result they are more or less liable to injury if cold weather occurs afterwards. On the other hand, they are less injured by early frosts because the longer summer of the milder climate and the late occurrence of autumn frosts permit them to complete their growth in good time. Similarly the less extreme cold reduces the danger of winter frosts.

When forest trees are young they are much more liable to frost damage than later on, so that protective measures are mainly concerned with regeneration. The extent to which such protective measures are necessary varies greatly. In the first place it depends upon the locality. As the local incidence of frosts varies considerably and certain sites are specially liable to severe and frequent frosts, the importance of preventive measures is naturally greatest in these localities.

The chief measures employed to reduce damage by frosts are directed towards hindering the fall of temperature by checking radiation of heat and evaporation and also by providing for the conducting away of cold air from the place to be protected, so that it does not accumulate and stagnate on the ground. An additional precaution is the employment of frost hardy species in localities prone to suffer severe frosts. In regard to the selection of such species, it should be noted that the behaviour of species to late frosts and summer frosts, on the one hand, and autumn and winter frosts on the other, may be very different. Moreover, it is now recognised that within the species, especially such as have a wide natural distribution, there are local races which exhibit differences in behaviour as regards frost.

The following are some of the measures which may be adopted :

The raising of the young crop under overhead or side shelter from the old one. Overhead shelter, though effective against frost, has the drawback that the exclusion of light keeps back the growth of the young plants so that they emerge from the " frost layer " later. Side shelter, or better, a combination of side and overhead shelter, as in the strip shelterwood systems, is probably preferable. Coupes in the clear felling system should be narrow strips. In nurseries, shelter can be given to the beds by screens

of branches, laths or lattice work which can be placed over them in frosty weather. Smudge fires, whose smoke hinders radiation, may also be employed. The removal of excessive grass cover, at least near the young plants, is advisable because grass radiates heat very strongly.

Wet localities should be drained before planting or regeneration. The retention, so far as danger from wind permits, of a belt or strip of old trees on the east and north sides of the area to check cold winds, may be helpful.

Provision should be made for air currents so as to avoid stagnation of cold air, by such measures as: pruning deeply branched trees, removal of thickets of advance growth, cutting gaps through woods that cross the line of valleys.

(2) *Frost Cracks.*—These are longitudinal splits in the stem caused by winter frosts, generally in conjunction with wind. When they are healed over they are called *Frost Ribs*. They are due to the rapid contraction of the outer layers of the wood during very cold weather, and are especially liable to occur when the temperature falls very rapidly after the sap has begun to rise in late winter. Wet soil and northerly and easterly exposures favour this form of frost damage.

Preventive measures consist of the drainage of wet areas, the formation of shelter belts on northerly, easterly and south-easterly edges of woods, the retaining of a closer strip on the above-mentioned edges of seed and secondary fellings in sensitive species, and avoiding the practice of holding over standards (oak, etc.) on sites prone to this form of frost damage.

(3) *Frost Lifting.*—It is often noticed that, in late winter and early spring when sharp frosts at night alternate with thaws during the day, young plants in seed beds and nursery lines, as well as in sowings in the open, are lifted out of the soil and lie prostrate on the surface. This is due to the soil rising under the influence of frost, carrying the young plants with it, and when the thaw comes, sinking again, leaving the plant slightly higher than before. The phenomenon is confined to young plants in their first or second year, and especially affects the shallow rooted species, *e.g.* spruce, silver fir, birch, alder, beech, hornbeam, ash, etc. The deeper rooted oak, sweet chestnut, walnut, etc., and, generally speaking, Scots and Corsican pines escape.

The danger is greatest on moist soils, on south-west and south-east slopes, on which night frosts and warm days are commonest, on moist, humose and peaty soils in which frost penetrates deeply. Dry sands are least prone to this form of frost trouble.

Preventive measures include: drainage of wet soils, employment of planting in place of sowing in endangered localities, re-

tention of natural soil covering as far as possible, especially moss, if present. In the nursery, clay soils should have ¼ to 1/3 sand mixed with them, beds should be raised to facilitate drying, drill sowing should be preferred to broadcast sowing and the ground between the drills covered with moss, litter, sawdust or other non-conducting material. Autumn weeding should be avoided, the removal of harmful weeds being done by cutting rather than uprooting so that the soil is bound together by grass roots. Plants should be earthed up in autumn by spreading fine earth through a riddle until they are half covered. Plants lifted by frost should be replanted as soon as possible in order to prevent drying out of their roots. The beds should have fine earth sifted over them so that the plants stand as deeply in the soil as before.

Protection Against Heat and Drought

Damage done by Heat and Drought.—The outward appearance of plants and parts of plants killed by overheating and drought is often similar to that produced by frost. Excessive heat acts like frost in causing molecular changes in the protoplasm. The surface soil, in certain conditions of weather and locality, is warmed up by solar radiation so that plant tissues are killed at the point of contact with the soil. Young succulent stems of seedlings generally fall over. In older stems, already lignified, growth may continue for a time above the withered base. As certain fungi often attack the damaged part, the subsequent death of the plant is apt to be put down to the action of the fungus, though, in fact, the overheating of the surface soil is the primary cause.

Though overheating may be the cause of the death of some plants in hot seasons, generally speaking, at any rate with older plants, most of the damage done is due to the effect of *drought.* The sunshine increases evaporation and causes a greater or less loss of water. The balance between evaporation and intake of water in the plant becomes upset. The former increases and the latter is reduced if the hot weather continues for long.

High temperatures and drought prevent the germination of seeds by withdrawing the water necessary for the process, kill seeds, seedlings and older plants and occasionally even older trees, singly or in groups. Even when, in the case of older trees, actual death does not result, growth is checked and loss of increment produced. The premature leaf fall, caused by drought, deprives the trees of considerable amounts of nitrogen and phosphorus as the withered leaves contain nearly as much again of these important substances as the normal autumn leaves. Drought also increases the fire hazard and drought-enfeebled

plants are more susceptible to the attacks of insects and fungoid pests.

Broad-leaved trees are on the whole more resistant to drought than conifers and deep rooted species than shallow rooted ones. Seedlings and small plants are most liable to be injured by overheating and later to suffer from drought. The conditions of the locality greatly influence the age to which this danger extends. In poor, especially only slightly moist soils, shallow soils and on southerly slopes without side shelter, not only young regeneration and thickets, but even young pole wood may die off.

Precautions Against Heat and Drought.—Natural regeneration under a shelterwood is preferable to artificial sowing. If planting is necessary, it is better to use deep-rooted transplants rather than seedlings direct from the beds. The soil should be cultivated deeply in order to promote the growth of deep roots and to improve its water-holding capacity. In the nursery, hedges and temporary screens may be provided to shelter the beds. Beds of seedlings may be protected by screens or branches at the hottest time of the day. The beds should be kept free of weeds as weeding prevents the soil from caking. The space between plants should be hoed in hot summers, even if there are no weeds. Plants may be watered, but when this has once been done, it is necessary to repeat the operation at intervals until rain falls, because the surface roots whose formation is encouraged by watering soon die if the soil becomes too dry.

Standing crops should be kept as dense as possible and the natural soil covering preserved. Trees on the outer margins of woods and along rides should be kept dense and the outer row encouraged to branch low down to keep hot dry winds out of the forest. In order to retain rain water, horizontal ditches may be dug along dry slopes.

Seed fellings on dry soils should be kept dense until a good crop of seedling is established and then opened fairly quickly to allow the young plants to grow up through increased access of light, dew and rain.

The orientation of the felling front and the making of fellings in the form of narrow strips, so as to take advantage of the shelter given from the sun by the uncut margin of the forest has already been mentioned when speaking of marginal conditions.

Bark Scorching.—This is a form of injury which consists of the killing of a patch of the rind of a tree through exposure to the direct rays of the sun, whereby the temperature is raised to a degree fatal to the living cells of the bast and cambium. The injury is most frequent on the S.W. and W.S.W. sides of the stem. The bark dries up and later falls off and the exposed

sapwood becomes brown and is generally attacked by rot producing fungi. The damage extends to a greater or less extent into the wood so that the value of the stem is reduced.

Bark scorching affects chiefly trees which have a smooth, thin bark without fissures. The taller the stem and the higher the crown, the more the stem is exposed to bark scorch. Large stems suffer most because they offer a larger expanse to the direct rays of the sun and do not radiate heat so freely as smaller ones. Trees which stand in the open, especially those isolated after having grown in dense woods are most liable to injury from bark scorch.

Preventive measures consist in avoiding the sudden exposure of spruces, beeches and other thin barked trees to the W., S.W. and S., mixing thick barked species with beech, allowing marginal trees to branch and avoiding high pruning of beeches in exposed positions. Trees that are suffering from bark scorch should not be felled if they shelter other trees behind them which would become liable to the same danger if exposed.

Protection Against Wind

The injuries done to the forest by wind have already been briefly described. They include the physiological and pathological effects of over-transpiration and the constant bending and shaking of plants and plant organs, the blowing away of leaf litter and the drying out of the soil due to persistent winds as well as the uprooting and breakage of stems by storms.

In western and central Europe, south-westerly winds are prevalent, especially during the autumn and winter. Strong south-west winds cause a stunted and misshapen growth of trees, especially near the sea coast and on the exposed borders of woods. Moist winds injure trees near the sea coast by the salt they carry, both directly and through the soil, into which the salt is washed by the rain. Easterly and north-easterly winds prevail generally in the spring. They are cold and dry and cause injury to young plants and the foliage and flowers of trees as well as drying the soil.

Broad-leaved trees suffer more than conifers from dry winds. Tender young foliage and flowers are often shrivelled by north-east winds. Seedlings and small plants, especially when recently planted, suffer severely from dry winds until a cover is established.

Protection Against Persistent Winds.—The maintenance of a good leaf canopy is the most important measure. In exposed places, natural regeneration, selection fellings and the formation of protective belts are advisable. If planting is done during dry east winds, special precautions should be taken not

to expose the roots of the plants to the air. In order to check the passage of winds through the woods, evergreen conifers should be mixed with broad-leaved trees, and belts of them established on the exposed sides of woods, the outside trees being encouraged to branch down to the ground. Undergrowth springing up on the easterly and north-easterly boundaries of the forest should be preserved. Coppice should be cut from west, south-west or north-west towards the opposite points of the compass, in order that the young shoots may be protected from dry cold winds.

Wind Storms. — The damage done by storms of wind consists not merely of the uprooting of trees (wind fall), and the breaking over of stems (wind break), but also the throwing of one tree on top of another. This makes the cost of clearing the ground very great. Much timber may be thrown on the market compulsorily and unexpectedly, so that prices are depressed. If there is much delay in removing the timber, there is danger from bark beetles (in the case of conifers) and a great growth of grass and weeds, which makes regeneration difficult. In addition, the working plan may be upset by an extensive wind fall, which may cause the extraction from the forest of many years' normal yield of timber, deplete the growing stock and necessitate the regeneration of woods which, in the ordinary course, would have remained standing for many years.

Conifers are more damaged by wind storms than broad-leaved trees. In Europe, the spruce suffers most—of others the Douglas fir and silver fir. Larch and pine are much more resistant. Evergreen trees are naturally more endangered than deciduous species, because storms are more frequent in the winter months, but a storm during the growing season may be disastrous to broad-leaved trees.

The resistance of trees to storms depends, not only on the species, but also on the conditions under which they are growing. A deep-rooted tree like the Scots pine or silver fir, growing on a shallow soil which prevents its normal development, is even more prone to be overthrown by the wind than a naturally shallow-rooted species in the same conditions. Trees which grow up in exposed conditions adapt themselves to resist wind by developing a strong root system, a sturdy but comparatively short stem and strong branches. Trees which have been grown in close woods, on the other hand, if afterwards exposed to the wind, are much more easily uprooted or broken.

Older woods are more frequently damaged by wind storms than middle aged or younger ones, and high forest is more endangered than coppice. In the Compartment System the isolated shelterwood trees are very apt to be damaged by wind and the

system cannot be employed in localities exposed to storms. Whether uneven-aged or irregular selection forest is more exposed to storm danger than the more even-aged forms, is largely a question of skilled management. Trees injured by game, insects, fungi, canker or bark scorch are very liable to breakage by the wind, generally at the place of injury.

The configuration of the ground has a great influence on the damage done by storms. Downhill currents are the most dangerous. When a wind storm passes over a mountain or an elevated plateau, it descends the slope on the other side and in mountain districts the upper slopes on the lee side are often more seriously exposed to damage than the windward ones.

Wind following a long period of wet weather is dangerous because the saturated soil does not give a good root hold. In the same way, naturally swampy and shallow soils lead to damage. Roots attacked by rot fungi give way easily.

Protective Measures.—Protective measures may be grouped under the following heads:

Strengthening woods by growing storm-resistant species in exposed positions, by mixing deep-rooted species with shallow-rooted ones, by developing sturdy individual trees by means of early, frequent and moderate thinnings, and by giving better rooting conditions through draining damp areas.

Sheltering woods, e.g. by encouraging marginal trees to branch down to the ground, by establishing and maintaining protective belts along the boundaries of the forest, using storm-firm trees and thinning them severely after early years to encourage sturdy growth.

Refraining from exposing trees which would offer little resistance to storm winds by making clearings and regeneration fellings in the form of narrow strips at right angles to the prevailing winds and proceeding always against the direction of such winds. The freshly exposed margin is protected by the uncut part of the wood. Exposed mountain forests should be regenerated on the Selection System. When the felling of an older wood will expose a younger one to danger from windfall, a *severance cutting* is required. This is a narrow clearing (40-50 ft. broad) made along the margin of the older wood next to the younger one in order to accustom the young wood to exposure. A severance cutting must be made before the wood that is to benefit is too old to respond to the increased exposure by strengthening the marginal trees. The cleared strip is at once planted up and after a few years may be widened by cutting and planting a second strip on the windward side of it. The young plantations themselves act as a protection to the wood behind them. Severance Cuttings are also employed in large even-aged

woods to provide, later on, more than one place in which fellings may be started and avoid too large felling areas. A strip of the old wood may be left when the felling is started as an additional protection to the wood which lies to leeward, the trees in the strip having some of their branches lopped off to reduce the danger of their being blown over.

Protection Against Heavy Rain

Heavy rainfalls may damage the forest by washing away dead leaves, soil and seeds; by uprooting young plants, such as seedlings and recently planted transplants; by destroying roads and ditches and by loosening the roots of trees.

Steep slopes with light, loose soil which is not covered by woody growth, herbage or dead leaves are the most liable to damage. Clay soils are apt to form an impermeable crust when subjected to heavy rain, which prevents air reaching the roots of plants.

Protective Measures.—(a) Maintain the forest growth and the natural soil covering of herbage, moss or dead leaves on slopes subject to denudation. Natural regeneration under a shelterwood, especially the Selection System, and the Coppice System protect the soil well. If planting is done the slopes should be terraced and the planting carried out in horizontal lines.

(b) Leaf catching and protective trenches may be dug horizontally on steep dry slopes.

(c) Extraction of stumps, pasturing of cattle, removal of litter and cultural operations, which loosen the soil, should be prohibited on steep slopes.

(d) Forest roads should have culverts and ditches kept constantly clear of litter, silt, etc., and banks liable to erosion protected by wattle work, sand fixing grasses, etc.

Protection Against Snow

The damage done by snow in the forest may consist of the crushing down of young plants and trees, the breakage of branches or stems, the pushing of young plants out of the vertical by movement of the snow on slopes or the tearing out of branches owing to the sinking of deep layers of snow into which their ends dip.

Damp snow, falling in large flakes, is apt to accumulate on the crowns of trees and by its weight bring about the bending and uprooting of trees or the breaking of their stems or branches. The damage done depends on the amount and nature of the snowfall and the weather, the species of trees and the form and density

of the crop. Dry powdery snow does not cling to the trees so readily, and is more easily shaken off by the wind than damp snow.

Broad-leaved trees are less liable to damage than conifers, as snow generally falls in the winter when their branches are bare and afford little lodgment, but serious injury can be done to them by snowfalls occurring early enough or late enough to catch them in leaf. The liability to snow damage of a species depends on the form of the tree. Species with pendulous and flexible branches are able to withstand snow best. Of the common conifers, the Douglas fir, Austrian and Scots pines and the spruce suffer most. It is now recognised that in the case of the Scots pine, and possibly other species, there are snow-resistant races which occur naturally in the mountains and northerly regions, whilst other races native to the plains and warmer districts are more liable to snow damage. The former have spirelike crowns and slender branches, whilst the latter have broad crowns and heavier and more brittle branches. The spruce is more resistant than the pine to snowbreak, but bulks largely in statistics because it forms extensive forests in snowy regions.

Even-aged woods with a level and close crown canopy are more liable to damage by snow than uneven-aged and more open woods. Young pole forest is most endangered, especially when grown up in a crowded condition so that root systems and stems are weak. Groups and masses of young stems are bent over and crushed down by the weight of snow on the crowns. Older woods suffer more from the breakage of the crowns and stems of individual trees. Uneven-aged woods and open woods allow more of tne snow to fall to the ground and the wind has a greater opportunity of shaking the snow from the trees. A strong wind springing up after the crowns of trees are laden with snow may cause very great damage.

Protective Measures. — (a) Mix broad-leaved trees or larch with evergreen conifers.

(b) Carry out early, frequent and moderate thinnings so as to strengthen the individual stems and allow the snow to fall between the trees and to be shaken off their crowns.

(c) Raise uneven-aged woods.

(d) Cut bracken, long grass, etc., round young plants before winter, so that snow may not crush their leaves down on the young plants.

(5) OTHER INJURIOUS INANIMATE AGENCIES

Besides the damage done by climatic conditions, the forest is subject in certain circumstances to injury by floods, torrents, and excessive water in the soil, shifting sands, land-slides, acid fumes

and smoke and other non-living agencies. Some of these phenomena may be due to causes operating outside the forest area, as, for example, torrents due to the melting of snow or to heavy rainfall above the forest limit, drifting of sand from the sea shore, production of fumes from industrial establishments in the neighbourhood; or from conditions arising within the forest itself, *e.g.* configuration of the land and geological features causing accumulations of water, breaking of the forest and soil cover permitting the movement of sand. It is proposed to deal with these special and less widespread forms of damage very briefly.

Control of *floods* and torrents may call for engineering works of considerable magnitude. The value of the forest cover in the collecting areas of streams and rivers for moderating the run-off has been described already and the afforestation of such areas is one of the most important measures of prevention in many cases. The sides and beds of torrents may be strengthened by revetments and the force of streams reduced by terracing their beds.

Inundations in valleys and plains are generally caused by the melting of snow in the mountains or to heavy rains. They may be aggravated by the deforestation of mountain areas or the faulty management of protective forests. Generally, the work necessary to prevent inundations is too great a task for any private individual and must be taken in hand by the State. The cost of the works and their maintenance is great and afforestation has often to be carried out over large areas and often in very difficult conditions.

In forests subject to inundations it is necessary to employ species which will stand a good deal of moisture and occasional immersion. Pollarding, the Selection System and coppice with standards are suitable silvicultural systems.

Swamps and permanently wet areas may be *drained,* but before deciding on drainage careful consideration must be given to the effects of drying the swamp on adjoining land. In mountain regions swamps often form valuable sources of water for lower slopes during dry weather. Forest growth itself reduces the wetness of the soil and many swamps are caused by the destruction of the forest. Extensive draining operations are generally unwise, but for small areas, draining carried out by a system of open ditches is generally suitable.

Drifting sands are most common on the sea coast, but may also occur inland where a loose, sandy soil is exposed to the action of the wind. In the forest they are generally due to the destruction of the tree and the ground cover, and it is obvious that measures which may lead to this must be avoided. The maintenance of the forest on sandy hills is the chief protective measure against inland sand drifting. Extensive clearings must

be avoided and the Selection System or a shelterwood system is desirable. Natural regeneration is, however, not always possible on dry sandy soils. In the case of artificial regeneration, planting is preferable to sowing, but the planting holes should be small and small plants used. Underwood should be protected and the windward side of the forest kept dense. Pasturage, the removal of grass or litter, etc., should be prohibited. Loose sand may be fixed by fences or by covering it with branches or sods. Fences may take the form of stakes driven into the ground supported alternately on either side by structs, and branches of pine, broom or other suitable material interwoven, leaving large interstices through which the sand may pass, otherwise the pressure will break the fence. Various materials may be used to cover the sand, *e.g.* sods, weeds, grass, straw, seaweed, rushes, etc., according to what is available. After the sand has been fixed, it should be planted, unless this has already been done before the covering is placed in position. Pines are, in general, the most suitable species.

The fixing of drifting sands on the sea coast is generally more difficult, because of the constant supply of sand from the sea and the persistent salt-laden winds. It is necessary to form a protective dune which will itself be stable and sufficiently high to prevent much sand drifting over it. The formation of such dunes, and their maintenance by the use of sand grasses and other dune vegetation, and the planting of forest trees on the leeward side of the dunes are special technical operations which it is not proposed to describe here.

Fumes and *smoke* injure trees near industrial areas. The chief deleterious material in the atmosphere in such cases is sulphur dioxide. Some other chemicals present in the smoke and furnace gases of certain manufacturing plants, such as mercury, hydrochloric acid, oxides of nitrogen and chlorine are also injurious. Generally speaking, conifers are more sensitive to smoke and fumes than broad-leaved trees, possibly because the leaves of evergreens are exposed for several years to the fumes, whereas deciduous trees renew their foliage every year. There is some difference of opinion as to the relative sensitiveness of various species. Little or nothing can be done in the forest where the damage is acute and recourse must be had to any laws which may exist to compel industrial concerns to abate the nuisance by suitable technical measures. In less acute cases, the growth of the less sensitive species in the affected areas is practically all that can be done to mitigate the damage.

PART III

FOREST ECONOMICS

CHAPTER V

FOREST VALUATION AND FINANCE

1. **Definition.**—Forest Valuation deals with the value of forests as productive assets: it involves in the first place the determination of the quantity of material produced, this quantity being measured by methods described under Forest Mensuration. Forest Finance deals with the relations between values and costs. The two subjects are closely inter-related and cannot be conveniently separated in the following brief review of the problems involved. The purposes for which forest valuation is used are as follows:—

To determine the value of a forest as an investment.

To compare the results, quantitatively and financially, of
- (a) different silvicultural treatments,
- (b) varying lengths of rotation (the period elapsing between the formation of a wood and its final harvesting),
- (c) growing different species.

To judge between the claims of forestry and agriculture for the use of certain land.

To assess the compensation which should be paid on account of damage to forests and their produce,

To ensure a sound economic foundation to the practice of forestry.

It should be noted, however, that it is seldom possible to establish an exact and indisputable money value for a forest based on its productive capacity as in the case of a factory. The reasons for this are difficulties in making exact measurements, unforseeable events affecting crops, which take a long time to mature, and changes in costs and prices. It is important to bear this in mind in considering, in any individual case, the extent to which forest policy, and choice of species, silvicultural system

and rotation should be based on valuation. The point is referred to again later in section 9.

2. **Capital, Receipts, Expenses and Profit in Industry.** — In every industry there are expenses, receipts and profits (or losses). Expenses are separated into *capital* and *current* (or annual) expenses. Capital expenditure is the initial cost of the plant and site, and the cost incurred in replacing the former when worn out or obsolete. Current expenditure is the annually recurring expenditure incurred on working and maintaining the plant and producing the products for sale. Current expenditure may again be subdivided into overhead and direct expenditure. Overhead expenditure is the cost of administration, supervision, etc., which is independent of the quantity of produce manufactured and sold. Direct expenditure is the cost, which varies according to the out-turn, of producing the manufactured articles and placing them on the market. An important item in overhead expenditure may be the interest on a loan raised for the construction and equipment of the factory. Receipts will for the most part represent the amounts received from purchasers for the goods sold, but may also in some cases represent capital, when plant no longer required is disposed of. Profits in industry are generally calculated annually and represent in the first instance the excess of annual receipts over annual expenditure. Changes in the capital value of the factory during the year must, however, be taken into consideration in assessing the actual profits, and generally a sum on account of depreciation will have to be deducted from the profits as calculated above. The first requirement in order to obtain profits is the investment of capital, and the value of the profits must be assessed in relation to the amount of capital invested. Thus the true value of the profits is shown, not by their amount, but by the rate of interest which they represent on the invested capital. An important factor conducing to success in industry is that the capital invested should be neither more nor less than is necessary to obtain the maximum efficiency in the production of marketable goods. If an industry is over-capitalised the profits will not represent a remunerative rate of interest on the capital employed. If it is under-capitalised, the introduction of fresh capital may result not only in increasing the amount of profit, but also in raising the rate of interest earned on the total capital.

3. **Capital, Receipts, Expenses and Profit in Forestry.** —When a forest is established by artificial means the situation, with some important modifications, resembles that in industry. The differences lie in the nature of the capital in forestry and the fact that the returns are delayed so that the investment will not be fully productive until a forest, containing woods or trees of all

ages, has been built up. The capital invested in forestry, in so far as it is composed of the value of the land and the cost of formation, is, at the time of formation, similar to that invested in industry. The bulk of the capital assets is, however, represented by the growing stock, and the bulk of the capital cost by the interest accruing on all expenditure up to that date, many years after formation, when a wood is ripe for felling. Thus a single wood has investment features resembling a provident fund, to which annual subscriptions are made which accumulate at compound interest to provide a certain sum at a certain age, the place of the subscriptions being taken by the annual increments. On the costs side the rate of interest may be regarded as fixed, as in the case of a provident fund. On the assets side, however, the wood increment, which represents the interest, accrues at a constantly *decreasing* rate throughout life; in other words, the ratio of the wood increment during any year to the volume at the commencement of that year is a steadily falling quantity. *Fig.* 1 illustrates the fundamental difference between a growth curve and curves representing a sum accumulating at a steady rate of interest. The volume curve shows the actual volume of wood at various ages and the interest curves the volumes which would be attained if a wood, having a volume of 400 c. ft. at its first measurement at the age of 10, increased at the rates of 3% and and 5% compound interest per annum; incidentally the latter show the great effect of costs incurred in the early life of a wood on the financial results with long rotations.

A natural forest may be regarded as a going concern presented by nature. The income obtainable from it, however, is unlikely to be in proportion to its capital value and it is the business of forest management (*See:* Part IV) to plan future operations so as to bring about a proper adjustment of the latter. Even in such forests the compound interest factor has to be considered, as will be shown later.

4. **The Effect of the Rotation on the Forest Capital, Income and Yield.** — Reference has been made (Section 2) to the effect of under and over capitalisation in industry; it is principally through the rotation adopted that the forester influences the amount of capital invested in the forest and the amount of income received therefrom. The average annual income in wood from a tree or any unit of area is given by the quotient derived from

$$\frac{\text{volume of wood}}{\text{age of tree or trees}}$$

The information required for this calculation is obtained from volume and yield tables (*See:* Mensuration). If the above calculation is made for a number of different ages, the age which

results in the highest average wood income will be equivalent to the rotation which produces the maximum possible quantity of wood from a tree or any unit of area, and this holds good whether the area is occupied by a one aged wood or by a series of age gradations. This rotation is known as the rotation of the *maximum mean annual increment.* If the rotation employed is above or below this rotation, the project will, if the object is the maximum annual wood production, be over or under capitalised,

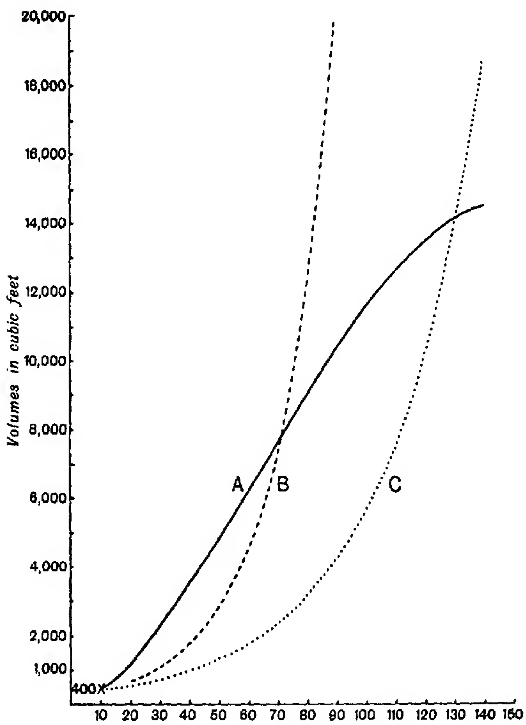


FIG. 1. Forest Capital Increment.

Curve A. Volume curve from a yield table for II Quality Spruce (Saxony).

" B. 400 cubic feet at the age of 10, increasing at the rate of 5% per annum compound interest.

" C. Ditto at 3% per annum compound interest.

with a consequent drop in the yield of wood per unit. The rotation which produces the largest quantity of wood will not, however, necessarily result in the largest gross income in money. Wood below a certain dimension, varying with circumstances, has no value, and, when it becomes marketable, there is generally a progressive increase in the value per cubic foot, known as the price increment. This price increment may be continuous, or it may advance by steps; as in the case when the timber reaches the minimum dimension required for some special purpose. If money values are substituted for volumes in the above calculations the rotation of the *maximum mean annual gross income* is found. Up to the present no consideration has been paid to costs on which the actual profits will depend. Such costs will be the value of the land, cost of establishing the crop and annual expenses, and, as has been already indicated (Section 3), the principal factor in the costs is the compound interest charges accruing on these items between the time they occur and the felling of the crop. A comparison of the cost and sale values of a unit wood (*See:* Next Section) will show the net profit and, if the calculation is made for different rotations, will indicate the rotation of the maximum profit. Since, however, the capital invested also varies with the length of the rotation employed, the rotation of the highest net profit per unit is not the rotation of the highest yield on the capital. The latter is known as the *financial rotation;* it is the rotation which results in obtaining the highest possible rate of interest (*financial yield*) on the capital employed. It is generally determined from comparisons based on soil expectation values (*See:* Section 6).

5. The Cost Value of an Even-aged Wood and the Effect of Costs on Profitability.— Before any profits can be obtained by the owner, the sale value of the crop must exceed its cost value as represented by all costs, plus compound interest charges, which have accrued from the time these costs were incurred up to the time when the crop is harvested. In determining this cost value the following are the principal items to be considered; there may be others, but they will be dealt with similarly.

The value of the land, S,

The cost of establishing the crop, C,

The annual expenses, e,

And, as a credit to be deducted from the above, the value of thinnings, T (N.B.—These are in effect a partial realisation, in the form of income, of accrued interest).

All these costs will increase in value up to the year for which the calculation is to be made—say for n years—at the rate of compound interest selected—say p.

A capital of £1 amounts in n years at p% compound interest to £$1{\cdot}0p^n$.

An annual payment of £1 will amount in n years at p% compound interest to £$\dfrac{1{\cdot}0p^n - 1.}{{\cdot}0p.}$

The land may be assumed, after the crop is cleared, to retain its original value, consequently only the accumulation of the compound interest charges thereon will be debitable to the crop, the amount during n years will be £$S \times 1{\cdot}0p^n - S$.

The charges on account of the cost of formation will be $C \times 1{\cdot}0p^n$.

Those on account of the annual expenses will be $e \times \dfrac{1{\cdot}0p^n - 1.}{{\cdot}0p}$

If a thinning having a value T is made in the year m, its value in the year n will be $T \times 1{\cdot}0p^{n-m}$.

The value of $1{\cdot}0p^n$ can be calculated by means of logarithms, but in practice foresters use tables similar to those used by Insurance Companies. In the 40th year after planting, with one thinning having taken place in the 30th year, the cost value of the wood would be

$$S \times 1{\cdot}0p^{40} - S + C \times 1{\cdot}0p^{40} + e \times \frac{1{\cdot}0p^{40} - 1}{{\cdot}0p} - T \times 1{\cdot}0p^{10}$$

In order to make such calculations of cost value and the necessary comparisons with sale values at different ages for assessing profits it is necessary to prepare *money yield tables* showing the anticipated sale values of the thinnings and final crop. These tables are prepared by substituting values for volumes in yield tables (*See:* Mensuration). In preparing the following statement Hiley's money yield table for II Quality European Larch (*Economics of Forestry* by Hiley) is used and cost values have been calculated by the above formula.

A Comparison of the Cost and Sale Values of 1 acre of European Larch II Quality.
S=£5 : C=£10 : e=12/- : p=4%.

Year	*Cost Value* £	*Sale Value* £	*Profit or Loss*	*Present value of Profits in the year 0* £
20	43	17	−26	
25	55	41	−14	
30	63	63	0	
35	74	86	12	3·04
40	90	110	20	4·17
45	108	137	29	4·96
50	127	160	33	4·64
55	149	183	34	3·93
60	186	205	19	
65	220	227	7	
70	260	249	−11	

The cost and sale values may be graphed as in *Fig.* 2.

It will be seen, from the graph, that the invested capital will yield a profit if the wood is cut down at any age between 30 and 68 and, from the table, that the rotation of the maximum net profit is 55 years. The profits in column 4 are, however, not strictly comparable, being obtained on different amounts of capital. They may be made comparable if they are all discounted to the year "0" by multiplying them by $\frac{1}{1{\cdot}04^n}$ (4% being the interest rate and "n" the year in which the profits are realised) vide the figures in column 5. It is now seen that the maximum financial yield is obtained with a rotation of 45 years. This will not, however, be accepted as the correct financial rotation owing to the fact that the calculations have been made with an arbitrary rate of interest. The true financial rotation would be obtained if a rate of interest were employed in the calculations which resulted in the cost and sale values being equal at one rotation only so that the curves in the graph (*Fig.* 2) would meet at one point but not intersect as shown below (*Fig.* 3). This rate of interest is the maximum which the wood is capable of yielding on the invested capital. Methods of determining financial rotations and yields are, however, usually based on soil expectation values vide next section.

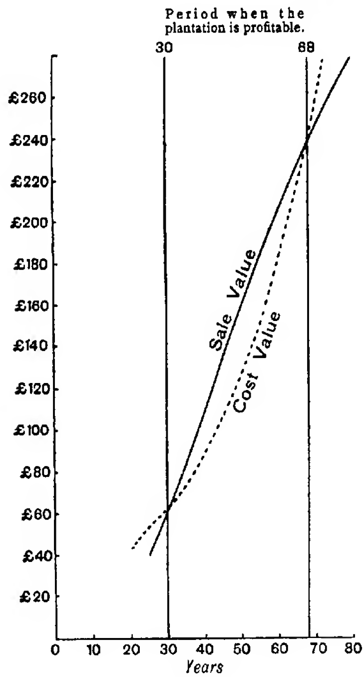


FIG. 2. Profitable Rotations.

6. **Expectation Values.**—The site of a properly managed commercial forest is a *productive asset* capable of yielding an income, rotation after rotation, theoretically for ever. The true

value of a productive asset is not what it has cost, but what it is capable of earning, and is found by discounting back to the present time all future receipts and costs and deducting the latter from the former. The *present value* thus obtained is, in the case of a forest site, known as the *Soil Expectation Value.* The rate of interest used in discounting the receipts and costs is the main factor affecting soil expectation values (*See: Fig.* 1) and, if the

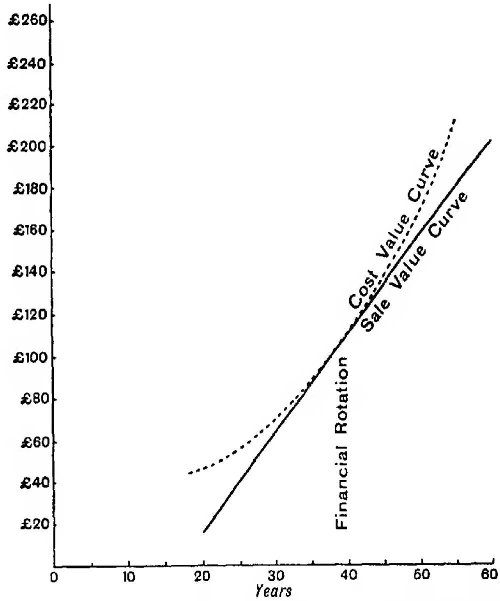


FIG. 3. Financial Rotation from Comparison of Cost and Sales Values.

rate is greater than the forest is capable of earning, the value will be a minus quantity. The soil expectation value is useful in determining the financial prospects of afforestation, since it will indicate the maximum amount which can be paid for the land in order to earn the rate of interest chosen. Similarly it may be used for comparing the value of the land for different purposes, *e.g.* forestry or agriculture (*See:* Section 8) or for growing different tree species.

The soil expectation value differs, of course, according to the rotation for which it is calculated, and the rotation which gives

the highest soil expectation value is usually regarded as the financial rotation, though, unless the rate of interest used in the calculations is approximately the same as the maximum financial yield (*See:* Section 5), this assumption is not quite correct.

The expectation value of an immature wood is sometimes calculated in order to determine the compensation which should be paid for damage or the price which should be paid for purchase. In this case the period for which the calculation is made will be the number of years elapsing before the wood will be mature.

7. Valuation of a Forest.—The method described in Section 5 may be applied to the valuation of the several woods in a forest which is composed of even-aged woods, and the cost value of the forest thus arrived at. In many cases, however, the necessary data for the calculation are not available, and, where age gradations or classes are intermixed, the method is not applicable. Any capital investment which yields a regular income, whether annual or periodic, may be valued by capitalising the income at a given rate of interest. Thus, if the annual income from a forest is £150 and $p=4\%$, then

since £4 is the yield of £100

$\therefore$ £150 is the yield of £$\frac{100 \times 150}{4}$ = £3,750, which is

the capital value of the forest.

The income which has been taken from a forest, particularly if figures are only available for a short period, may not, however, represent the true income that the forest is capable of yielding. There may have been over-cutting, so that the apparent income is really partly capital, or under-cutting, so that the income is capable of enhancement. Moreover, certain features of the management may be capable of improvement so as to obtain better financial results. A careful investigation into management is therefore essential before net income can be accepted as a basis of valuation. The principles governing the relationships between rotation, capital and yield remain, of course, the same, whether the age classes are separated or mixed, but in the latter case the actual relationships are much more difficult to determine.

8. Financial Comparison of Forestry with Agriculture.—It may be necessary to decide between the claims of forestry and agriculture to the use of certain land. Assuming, as is generally the case, that land capable of being put to agricultural purposes has well established sale and rental values, one of two methods may be adopted.

(a) The financial yield from agriculture is compared with the financial yield from afforestation (Section 4). Thus, if the

value of the land for agriculture is £6 per acre and the net rent (after paying all charges) is 4/-, the financial yield is $\frac{4 \times 100}{120} = 3{\cdot}3\%$. Selecting the tree species most suited to the locality the maximum financial yield from forestry is then determined and compared with the above.

(b) The maximum soil expectation value for afforestation (Section 6) is calculated for the species selected, using a discount rate equal to the agricultural per cent. (3·3 in the above case), and compared with the value of the land for agriculture. In the above case, if the soil expectation value is greater than £6, forestry will be more profitable than agriculture.

9. The Scope of Forest Valuation and Finance. — In the first place it must be stated that, in the case of natural forests from which most of the world's timber supplies are still drawn, the necessary data for making the calculations which have been referred to are generally non-existent. In other cases the fact that calculations are made on correct mathematical principles is of little avail if the data used are inaccurate (though it may be observed that cases arise where absolute accuracy is unimportant provided that relative accuracy, enabling different procedures to be compared, is obtained). The utility of financial calculations in forestry should, therefore, be considered in connection with the degree of reliability of the figures employed. The figures which are most open to doubt and which have the most influence on the calculations are (a) Interest charges and (b) Future receipts and expenses. The former influence most of the calculations in question and is the principal factor affecting the present value of the latter.

(a) *Interest Charges.*—Sometimes the rate of interest is indicated by the nature of the problem involved, as, for example, when the financial yield of agriculture is used to determine the comparative value of the soil for forestry (Section 8), so that the only source of inaccuracy lies in the estimates of future receipts and expenses. Often, however, the choice of an interest rate is a more or less arbitrary one; and the validity of the choice, when it is likely to be the main factor affecting the result, is likely to be called in question. For example, an initial expenditure of £1 on planting will, during an 80 year rotation, amount to £7·21, £23·05, or £105·76, according to whether the interest rate is 2½, 4 or 6%. In considering the question of interest rates we are entering into the domain of general political economy, and it is only possible here to suggest a few standpoints from which the matter may be regarded.

In the first place the question must be considered from the

point of view of security. The greater the security the lower the acceptable yield. In the case of an investment in, say, buildings, security depends on the possibility of insurance, or, the equivalent of this procedure, the spreading of risks. If the risk of a house being destroyed by fire is represented by a rate of 1% per annum on its value, the owner of 100 similar houses in different localities will gain nothing by insuring his property. Similarly, the owner of a large forest property will be protected by its size from losses, resulting from fire, wind, insects, etc., amounting to more than a small proportion of his annual income; he should, therefore, be satisfied with a comparatively low investment yield. The owner of a small property is differently situated and, since insurance of woods is difficult to effect at reasonable rates, he will require a higher yield in proportion to the speculative character of his undertaking. In the last century, when foresters first began to take an interest in forest finance, the yield obtainable on government loans was considered a reliable standard, and it was generally accepted that the yield from forests should be at a slightly higher rate. Since the Great War the yields obtainable on the loans of some European governments have risen to heights which can rarely be obtained from forests even under the most favourable conditions. Even in Great Britain it has been as high as 6%. These high yields, however, are not obtainable over long periods; they indicate insecure conditions and, either conditions improve, in which case the loans are replaced by others giving a lower yield, or alternatively there is repudiation and the lender loses both capital and income. Investigations into the financial results which have been obtained in the past from long established plantations should provide useful information both as regards the rate of interest which can be earned in forestry and the effect of changing values, referred to in the next sub-section; but few such investigations have been carried out.*

(b) *Future Receipts and Expenses.*—A fundamental defect in financial forecasts is that they are based on the assumption that money has a fixed value, *i.e.*, that its purchasing power in goods and services remains constant. Actually it has always had a fluctuating value—generally over long periods of time, a falling value, equivalent to rising prices of commodities and increased remuneration for labour. Such falls in money values are favourable to forestry because it deals with a commodity the production costs of which are incurred a long time before the article is sold. Thus, whilst the purchasing power of the 2½% yield obtained from

*The calculation was made in 1914 for the irrigated plantation at Changa Manga in the Punjab and it was found to have given a yield of 4·6% (Troup. *Silviculture of Indian Trees*). The conditions are, however, exceptional and the yield obtained cannot be considered a typical one.

the original investment of £100 in Consols is now considerably less than it was when the government loans were first consolidated, a cubic foot of oak timber has now a higher money value than it had, say 150 years ago, when the oak tree was planted. In the absence of other adverse factors, therefore, the comparative value of investments in forestry is likely to prove greater than financial forecasts, based on past average prices, indicate.

CHAPTER VI

FOREST MENSURATION

1. DEFINITION OF MENSURATION, AND OBJECTS OF MEASUREMENT

Properly speaking, forest mensuration includes the measurement of both forest land and forest products. The measurement of forest land, however, involving the survey, mapping and demarcation of forests is generally treated as a separate subject and called Forest Survey. In this work only the measurement of forest products will be dealt with.

Measurement may be required either for sale or for management purposes. Measurement for sale generally involves only the measurement of single trees and converted, or partially converted, produce.* Measurement for management purposes involves the measurement of trees, unit woods, or whole forests with the particular objects mentioned below:—

(i) *Measurement of Whole Woods and Forests.* — For the regulation of the yield (Chapter IX) and valuation (Chapter V) for which purposes it may be necessary to determine.

(a) The total volume of the growing stock, which may be termed the wood capital.

(b) The distribution of this volume in age or size classes.

(c) The increment; this being determined by successive measurements.

(ii) *Measurement of Sample Woods.*—Instead of measuring whole woods and forests for the purposes given above, samples may be selected and measured. Sample plots may also be measured for investigation into volume and increment at different ages, and, when the plots so measured are even-aged, they provide data for the preparation of yield tables (*See:* p. 164).

(iii) *Measurement of Single Trees* is required.

(a) as a basis for the measurement of woods and forests,

(b) for the preparation of *volume tables* (*See:* p. 158).

Trees are irregular bodies which generally have to be measured standing; their volumes, therefore, cannot be determined with absolute accuracy. The forester's aim is to select for measurement those dimensions which provide the best basis for the cal-

*Occasionally a sale is based on the measurement of a sample area.

culation of the volume and which at the same time can be most easily determined. Relative rather than absolute accuracy is sought. For sale purposes the volume of merchantable material is required; provided the basis of measurement is always the same, this can be calculated from the results of previous operations, or alternatively an estimate of the merchantable material may be made direct for each tree, being based on an easily determined dimension of the latter.

A tree consists of stem and crown, each of which provide a different kind of material for the market. The two parts are therefore measured separately. The upper portion of the stem may be included in the crown wood; the remainder of the stem is then usually referred to as the "useful bole."

In the following account only Section 2 refers to measurement for sale purposes, all the remaining sections refer to measurements for management purposes.

2. MEASUREMENT FOR SALE

A. The Felled Tree

(a) The Log.—The log is measured on the assumption that it is a regular body, the volume of which is given by the product of its mean sectional area in square feet and length in feet ($s \times l$). The sectional area referred to is generally the mid-sectional-area; but, in the case of piled logs, it may be taken as the mean of the two ends. The sectional area is obtained by measuring the diameter or girth and looking up the equivalent sectional area in tables, provided for the purpose, and based on the assumption that the section is a circle. Thus, length = 20′, diameter of mid-section = 15″, sectional area = 1·23 square feet.

Volume = 1·23 × 20 = 24·6 cubic feet.

In Great Britain it is customary to take the sectional area as being equal to the square of the quarter girth $\left(\frac{g}{4}\right)^2$, so that the volume in cubic feet, where the girth is measured in inches and the length in feet, will be obtained from the formula

$$\text{Volume in cubic feet } v = \frac{\left(\frac{g}{4}\right)^2 \times \text{length.}}{144}$$

Tables are used as before to avoid calculations. The quarter girth volume is about 78½% of the true volume.

The diameter is measured with a tree calliper, the girth with a tape, and the quarter girth with a special tape graduated to show quarter girths in inches and quarters. In Great Britain a cord is often used; it is folded four times and the four-fold length

is measured on a foot rule. The length is measured with a tape or rod.

To obtain the correct volume of the timber the log should be measured under bark. Bark allowances are sometimes made, when a thick barked species is measured over bark.

(b) Stacked Wood.— The material which is too crooked or too small to be sold in the form of logs or poles may be cut up and stacked. These stacks are made rectangular in shape so that their volume in cubic feet stacked is obtained from the product of their length, breadth, and height. The unit of measurement in Great Britain is the *cord* and such wood is often referred to as *cord wood*. A cord = 128 cubic feet stacked and the dimensions of the stack are usually made so as to produce this volume or a multiple thereof, *e.g.*, 8′ long × 4′ wide × 4′ high.

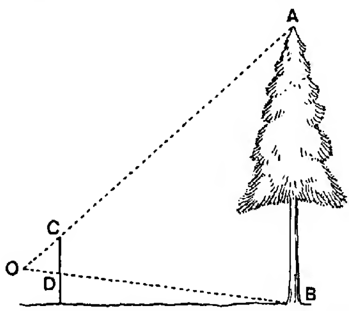


FIG. 4. Measurement of Height by Geometrical Method.

(c) Sawn Timber.—The length is measured in feet and the breadth and depth in inches. The volume in cubic feet is obtained from the formula

$$\frac{\text{Breadth in inches} \times \text{Depth in inches}}{144} \times \begin{matrix}\text{length in}\\ \text{feet}\end{matrix} = \begin{matrix}\text{volume in}\\ \text{cubic feet}\end{matrix}$$

B. THE STANDING TREE

For sale purposes the volume of the standing tree is estimated. The estimate may be in cubic feet solid—true or quarter girth measurement—, cubic feet stacked, or in converted material. The estimates are based on a knowledge of the measured volumes of felled trees, assisted usually by a measurement of girth or diameter and sometimes by a preliminary estimate of height or the length of useful bole. The girth or diameter is measured at a fixed point known as breast-height, which in Great Britain is taken as 4′ 3″ above ground level. Sometimes the volume tables referred to in the next section are used.

3. MEASUREMENT OF TREES FOR MANAGEMENT PURPOSES

A. Felled Trees

Felled Trees are measured in the same way as described for sale purposes; but, for the sake of greater accuracy, they are usually divided into short sections of 5 or 10 feet in length, and each section is measured separately.

B. Standing Trees

(a) Height Measurement. — For management purposes, particularly where statistical data which will influence the treatment of crops are required, the heights of standing trees may

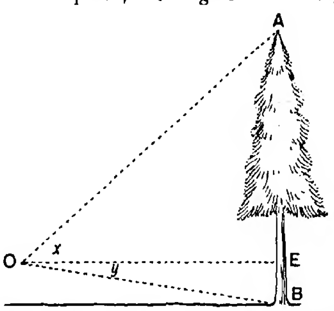


Fig. 5. Measurement of Height by Trigonometrical Method.

have to be determined with a considerable degree of accuracy. The instruments (hypsometers) used for the purpose are based on either geometrical or trigonometrical principles. The former depend on the formation of similar triangles as in *Fig.* 4. The lines of sight from the observer O to the top and foot of the tree respectively cut a plumb line CD at C and D, and ODC and OBA are similar triangles in which

$$AB : CD :: OB : OD$$

$$\text{and the height } AB = \frac{OB \times CD}{OD}$$

OB, the distance from the observer's eye to the foot of the tree is measured, and the lengths OD and CD, forming the arms of the instrument, are read off on the scales provided thereon. Using instruments based on trigonometrical methods the angles of elevation (x) and depression (y) are measured as in *Fig.* 5 and the height of the tree is obtained from the tangents of these angles. Thus the height

$$= AE + EB = OE \tan x + OE \tan y.$$

Where it is inconvenient to measure the distance from the observer to the tree a staff of known length is held against the tree and the distance computed therefrom.

(b) **Direct Estimate of Volume.** — The volume may be obtained by direct estimate as in the method described for sale purposes (*See:* p. 156).

(c) **Volume from Volume and Form-Factor Tables.** — The volumes of a number of felled trees which have been measured may be collected together in tables and these may be used in place of estimates. Since trees of the same girth and height may vary considerably in volume, these tables will not give accurate results for individual trees; but for a large number of trees they will give good average results, which is what is usually required. The tables may be prepared by girth or diameter classes (at breast height), or by one of these combined with height classes. An example is given below. In using such a table the girths would be measured and the heights estimated.

Extract from a British Volume Table for Larch.

Girth Class Inches	*Height in feet*			
	30-40	40-50	50-60	60-70
	Volume per tree in cubic feet			
8	0·08			
12	0·64	0·66	0·74	
16	1·40	1·58	1·80	2·10
etc.				

In place of volume tables, *form-factor* tables may be used. A form factor represents the relation of a tree's volume to the volume of a cylinder having the same *basal area* (sectional area at breast height) and height as the tree. The volume of a cylinder of basal area " s " square feet and height " h " feet $= s \times h$ cubic feet; the volume of the tree will be $s \times h \times f$, where f is the form factor. Form-factor tables are prepared from felled trees in the same way as volume tables. The form factor for the felled tree is obtained from the formula $f = \frac{V}{s \times h}$ where " V " is the volume of the felled tree as obtained by measurement. An example of a form-factor table is given below.

Extract from Lorey's Form-factor Table
for Timber down to 3″ in diameter.

Height in feet	*Scots Pine*	*Spruce*	*Beech*
20	·14	·18	·13
30	·32	·31	·21
40	·45	·41	·30
50	·48	·47	·40
60	·47	·48	·45
70	46	·49	·47

(d) Volume from Direct Measurement and Taper Tables. — For certain purposes, as, for example, for obtaining the volume of permanent sample plots (*See:* p. 165) woods have to be measured with a high degree of accuracy. This involves the very accurate measurement of a number of sample trees. If it is practicable to fell such trees before measuring them, it is much better to do so, but often this is impracticable. A ladder may be used and small trees may be measured in sections up to timber height by this means. For larger trees taper tables may be used. These are based on the fact that the stem of a tree is built up in accordance with certain laws (*See:* Metzger's theory, p. 59). Thus, if certain relations can be established by measurement, the taper curve, which will give the diameter of the tree at any point in its length, can be found. If it is possible by means of a ladder to reach half the height of the tree and measure the diameter or girth at this point (actually for certain reasons the measurement is made a little higher), the *form quotient,* on which the taper is found to depend, may be determined. The *form quotient* is ratio of diameter or girth measured at the above point to the diameter or girth at breast height. This method has only recently been taken up in Great Britain by the British Forestry Commission; but it is widely employed for conifers in some European countries, where also a method of deducing the form quotient from the size of the crown has been developed, thus avoiding the use of a ladder.

4. DETERMINATION OF THE AGE AND INCREMENT OF TREES

A. Definition

It is of importance to know not only the dimensions and volumes of trees, but also the rate of such growth in the past and its probable rate in the future. Increment may be described as growth in relation to time or age.

B. Age and Increment of Standing Trees

(a) From Records. — The only method applicable to all descriptions of trees is to have a record of the year in which the tree was planted and to record a series of measurements over the required number of years.

(b) From Annual Shoots and Rings. — Certain trees, as, for example, pines and firs, show distinct annual shoots marked by whorls of branches. The age of comparatively young trees may often be obtained with a fair degree of accuracy by counting such annual shoots. In the same way the height increment over a period of years may be determined (*See: Fig.* 6). In

most of the trees in temperate climates the annual growth rings are visible on a cross section of the tree, and the diameter increment for the last few years may therefore be determined by removing with a hollow-borer, which is screwed into the tree, a cylinder of wood. The length of the cylinder will represent the

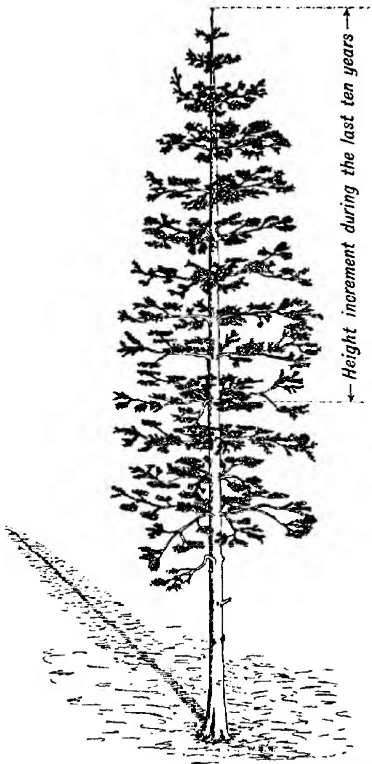


FIG. 6. A twenty year old conifer (diagrammatic).

radius increment for the number of years represented by the number of rings which can be counted on it, and, from this length and the present diameter of the tree, the diameter of the tree " n " years ago can be calculated. Given the diameter and height of a tree, the volume may be determined approximately by the use

of a form factor or from one of the formulæ which have been devised as a result of investigations into growth. Past increment, shown by the difference in dimensions at periodical measurements, may be used to estimate the future increment for a limited number of years.

C. Age and Increment from Felled Trees. Stem Analysis

Trees which show distinguishable annual rings contain within themselves their own record of increment, and, by felling them and cutting them into sections, an investigation into the past increment of every kind may be made. When such an investigation covers the whole life of a tree it is known as *stem analysis*. The following short account will explain the procedure. The first year's growth of a tree may be illustrated as a solid cone* and each subsequent year's growth as a hollow cone superimposed on that of the preceding year (*See: Fig.* 7), showing two years' growth with the first year's growth shaded. Thus, if a longitudinal section be taken through the centre of a tree, it will appear as in *Fig.* 8, illustrating a 60 year old tree with the cone representing each 10 years' growth marked. At ground level AB, 60 annual rings are counted, showing that the total age of the tree is 60 years. At CD 20 annual rings are counted, showing that the height above CD has been laid on in the last 20 years and that the tree reached this height in 60 – 20 = 40 years. Actually it is, of course, impracticable to split a tree longitudinally through the centre in this manner; but, by sawing cross sections at different heights, the data for drawing this diagram to scale may be obtained, and, from the diagram, the information required regarding the height, diameter and volume at any age. Thus, on any cross section, as CD, the number of rings counted on the section deducted from the total age of the tree will give the number of years in which the tree has reached this height and, by drawing an age-height curve from the data obtained from several sections, the height at any age can be determined. Suppose, for example, we wish to investigate the tree at the age of 50; the point F is found from the height curve which gives its

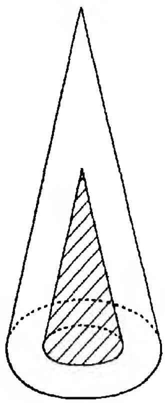


Fig. 7. First two years' growth of a tree (diagrammatic).

*The term cone is used for convenience in illustration. Actually the taper is never regular from the tip to the base; the cross sections in different parts of the length also vary and are seldom circular.

height above the line AB; the position of the points G and H are found by counting in 10 rings on the ground section (in practice the section is cut higher) from the cambium at A and B and measuring GH. From other cross sections, cut between F and AB, the positions of the necessary number of points, on the lines FG and FH, to fix the course of these lines is similarly determined by counting in 10 rings from the outside of the tree and measur-

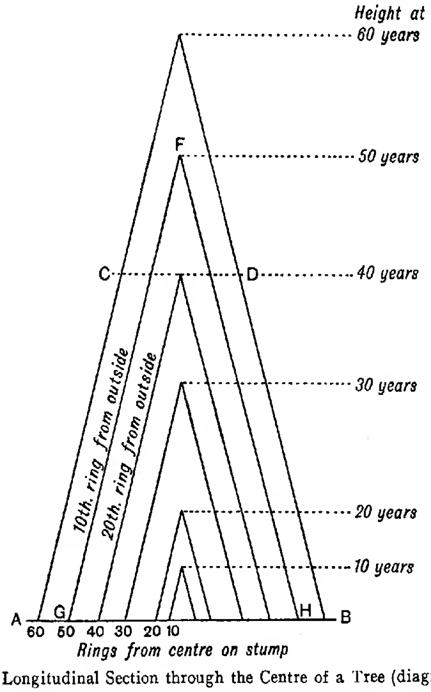


FIG. 8. Longitudinal Section through the Centre of a Tree (diagrammatic).

ing the resulting diameter.* When the figure FGH has been accurately drawn to scale it is clear that its volume can be computed. In practice the volume of the tree at various ages is usually computed arithmetically directly from the measurements made on the cross sections, cut for the purpose of the investigation.

*Since trees are seldom circular in section, the mean of 2 or more diameters is taken.

Stem analysis reveals *past* height, diameter and volume increment; by representing the data graphically in the form of curves, future increment may be forecast for a few years ahead.

D. Current and Mean Annual Increment

Increment may be expressed either as that laid on between two ages (current), or as the average laid on annually up to the present time (mean annual). Since one year is too short a period in which to measure growth, the current annual increment (C.A.I.) is usually taken as being synonymous with the average of a short period, say five years. It is a characteristic of normal growth that it rises rapidly and continuously in youth (*i.e.* each

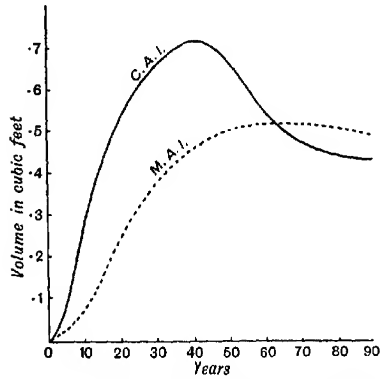


Fig. 9. Current and Mean Annual Increment of a Scots Pine tree.

year's increment exceeds the previous year's increment) and, having reached a maximum, it falls steadily. Thus, if a curve be drawn so as to represent the current annual increment, it will appear as in *Fig.* 9.

Since the mean annual increment (M.A.I.) is simply the average of the several current annual increments (being obtained by dividing the total volume by the age), its relation to the latter must necessarily be of the nature shown by the curve in this figure, that is to say it must be less than the C.A.I. as long as the latter is rising and for some years later, and reach a maximum at the time when it is equal to the C.A.I. Also, it is clear that, if the tree is felled at the time when the C.A.I. = M.A.I., and when the latter has therefore reached its maximum, it will be

felled at that age when its volume represents the maximum yield per annum. These relationships between the C.A.I and the M.A.I. are therefore of interest to foresters. An unfavourable season for growth, or an injury to the tree may cause a temporary fall in the rising curve of the C.A.I., but the effect of the former will generally be eliminated by taking the C.A.I. as the mean of a short period.

5. MEASUREMENT OF CROPS

A. Basis of Measurement

The measurement of woods and forests involves the measurement of the single trees of which they are formed. It is clearly impossible in practice to take, for every tree, every measurement which is required to determine volume. The methods used vary according to the purpose for which the measurements are made, but the general principle is to measure the most easily determined dimension (girth or diameter at breast height) of all the trees on either the whole area or on sample areas, to divide the trees into size classes and to determine the volume of the classes, either by the measurement of sample trees or from volume tables. The methods may be considered under the three following heads.

B. Measurement of Unit Woods for the Preparation of Yield Tables

A yield table is a tabular statement which gives the course of development of an *even-aged* wood of a given species up to a certain age, usually at intervals of 5 or 10 years. In forest management yield tables are used for the following purposes:—

(i) To determine volume at any age.
(ii) To determine increment at any age.
(iii) To determine quality of locality.*
(iv) To determine the most profitable species, method of treatment and rotation, for any locality.
(v) To determine the value of the soil, growing stock or both (*See*: Valuation).
(vi) To determine the yield.

A yield table gives the necessary data for the above purposes for a fully stocked unit of one acre. The yield table for Larch given below will explain the matter.

*Foresters divide localities into quality classes according to their productive capacities in relation to a certain tree species.

British Forestry Commission Yield Table for European Larch

Age	Main Crop						Thinnings	
	Mean Height	Mean Quarter Girth	Number of Stems	Basal Area	Form Factor	Volume	Number of Stems	Volume
Years	Ft.	Ins.		Sq. ft.		Cub. ft.		Cub. ft.
				Quality Class I				
20	40	4	900	98	·398	1,560	—	—
25	50	5	670	114	·403	2,300	230	155
30	58	6	520	126	·397	2,900	150	190
35	65	6¾	420	134	·394	3,430	100	220
40	71	7½	350	140	·390	3,880	70	245
45	76	8¼	295	144	·389	4,260	55	270
50	80	9	260	148	·386	4,570	35	290
55	84	9¾	230	151	·384	4,870	33	315
60	87½	10¼	205	153	·383	5,130	25	330
65	91	10¾	185	155	·383	5,400	20	325
70	94	11½	170	157	·382	5,630	15	290
75	97	12	158	158	·382	5,850	12	250
80	100	12¼	150	159	·382	6,070	8	210

The woods measured for the preparation of yield tables are known as sample plots and are usually laid off on the ground in the form of small rectangles. In order that the data may be serviceable the woods must be fully stocked, or nearly so, and this requirement generally results in their being less than an acre in extent. Sample plots may be temporary or permanent. In the former case a number of plots of varying age, covering the age-range required, are selected. These are measured and the yield tables may be prepared immediately. Permanent plots are selected when young and measured at intervals throughout their life. Temporary plots have the advantage that the work of preparing yield tables is expedited, and that it may be permissible to fell the plot and thus measure all the trees with greater ease and accuracy. On the other hand, woods measured for the preparation of a yield table must belong to the same quality class and it is not always easy to determine the quality at once by inspection; further, temporary plots do not enable a comparison to be made of the effects of different methods of treatment. The volumes standing on permanent plots are generally determined by measuring the breast height diameter or girths of all the trees, dividing them into size classes, and making volume measurements of sample trees in each class. Usually sample trees are measured after felling; such trees being obtained from thinnings or in the crop surrounding the plot. If suitable trees are not available for

felling, the method of direct measurement and use of taper tables for standing trees, as described on p. 159, must be resorted to.

Current annual and mean annual increments can be calculated from the yield table and the relations between these two increments are in essentials the same as those of a tree (*See:* p. 163); the removal of part of the volume in the form of thinnings introduces an irregularity into the increment curves (*Fig.* 9), which, however, is seldom of much practical importance. It will be observed that the true mean annual increment of a wood cannot be determined unless the volume removed in thinnings throughout life is known, and that the calculation of the current annual increment should take account of the volume removed in thinnings between two measurements.

C. Measurements of Sample Areas for Stock-taking Purposes and for the Determination of Increment

These sample areas should represent average samples of the woods or forests of which they form part. They are generally of considerably greater extent than the sample plots used for yield tables and may take the form either of rectangular or circular plots, or long strips, representing as it were cross sections through the forest. Before starting measurement it must be decided what is the smallest sized tree which should be included in the measurements and the limits of the size classes to be measured. The trees may then be measured and booked as below:

Extract from a Field-book for Measurement of Standing Trees.

Diameter, Class in inches	*Detail*	*Total*
6-12	~~||||~~ ~~||||~~ ~~||||~~ ||	17
12-18	~~||||~~ ~~||||~~ ~~||||~~	15
18-34	~~||||~~ ~~||||~~ ||	12
etc.		

The volume of each class will be determined from volume or form-factor tables, if available, or by more detailed measurements, preferably after felling, of sample trees. The current annual increment may be determined by successive measurements.

D. Measurement of Whole Woods and Forests. Stock-taking

If the forest is composed of even-aged woods and yield tables are available, its volume may be determined by measuring, on the ground or on maps, the areas occupied by each age class and

quality class, and determining the volume from yield tables. Since the latter give volumes for fully stocked areas, the density of the actual stocking will have to be assessed and the computed volumes reduced accordingly. If the forest is not composed of even-aged woods, an inventory of the crop will have to be made and the volume calculated from volume tables or sample trees. Where cost prohibits a complete inventory, only sample plots or strips will be measured (*See:* last heading). The percentage of the area which must be measured in order to obtain the desired degree of accuracy is first considered and the number and size of the plots or the width and distance apart of the strips fixed accordingly.

CHAPTER VII

FOREST UTILISATION

1. The Products of the Forest and their Use

Primitive man was, in the first instance, entirely dependent for his existence on natural products, of which forests were the chief source. Though the development of agriculture and industry through the ages have provided other sources from which the primary necessities of life are drawn, yet the demand for forest produce per head of the population increases steadily with the advance of civilisation. Stone, brick and steel may replace a large proportion of the timber used in building; coal, oil and electricity may replace wood fuel; wool and cotton may replace the skins of wild animals for clothing, and domestic animals and field crops the wild animals and fruits of the forest for food. Nevertheless, more timber is required for the larger houses of civilisation and for the multitudinous demands of civilised life; wood charcoal, gums and resins become indispensable for certain chemical and other manufacturing industries; wood bark and certain fruits of the forest are required for tanning; wood pulp finds an ever-increasing market for the manufacture of paper, cellulose and artificial silk, and so forth. Superficial observers, noting the substitutes for wood which are constantly being introduced, but failing to take account of the new processes which create for it new uses, frequently assert that there is no future for commercial forests. Such assertions are dangerous, if left uncontradicted, as they may influence, and probably have on occasions influenced, forest policy. The truth is, of course, that the problem which confronts foresters, as a result of new inventions, is not a reduced demand for forest products, but a change in the nature of the demand. The statement that the *per capita* consumption of forest produce progressively increases with advancing civilisation is supported by statistics.* Thus, the increase in the consumption of timber in the last few decades before 1923 was 0·1% per annum in France, 1·8% in Great Britain, 1·4% in Germany, 2% in Belgium and Italy, and 1·6% in the U.S.A.

*These data are taken from Zon and Sparhawk *Forest Resources of the World*. 1923.

These countries use nearly two-thirds of the sawn timber consumed in the world and the weighted average of the above figures indicate 100% increase in consumption every fifty years. Increase in consumption in these countries cannot be expected to continue on the same scale in the future, since there are indications that the *per capita* consumption has already reached its maximum, and, in the U.S.A., where supplies have been depleted through wasteful use, it has already been falling since 1906. Any further increase in the demand for sawn timber depends, therefore, on increases in population or on an improvement in the standard of living in the less advanced countries. The *per capita* consumption of timber is, for example, 25 times as great in Great Britain as in India (figures in India depend largely on estimate). The *per capita* consumption of wood pulp in the U.S.A. increased by 40% between 1910 and 1920; the *per capita* consumption of wood pulp for newsprint in Spain is only 1/7th of that in Great Britain. Such facts indicate a large scope for increased world consumption of forest products. The demands on forests must be considered in relation to the different kinds of forest products (*See:* Silviculture, p. 63). Some of the minor forest products provide the raw material of several important industries, but it is beyond the scope of this work to discuss their specialised forms of utilisation. Wood, the major forest product, may be put to direct use (in which case we apply to it the term *timber*), burned in the form of wood fuel or treated by processes which destroy it as wood and yield such substances as cellulose, acetone, charcoal, gas, etc.* These processes, important as are the demands they make on the forest, cannot be dealt with in a work of this character. Timber is the most important product of the forest. Owing to the complexity of its structure and the infinite variety of material provided by trees of different species, timber provides a substance with a unique combination of qualities, difficult or impossible to reproduce in a manufactured article; these qualities are, briefly, ease of working, attractive appearance, non-conductivity, elasticity, strength combined with lightness, and general adaptability. Even where strength or durability are the only requirements, timber is not necessarily inferior to iron and steel. For example, steel beams used in a " fireproof " building may collapse, when the con-

*Wood of small dimensions from broad-leaved species such as was formerly used for fuel, is now in increasing demand as the raw material for the production of acetone, which is used for explosives and in the textile and leather industries, acetate of lime used in the paint and other industries, wood alcohol employed as a solvent for cellulose paints, and activated charcoal used as a purifier in the chemical industries and for gas masks. It has also been demonstrated that motor-cars can run conveniently and efficiently on wood or charcoal gas, generated on the car itself, at a fraction of the cost of petrol.

tents of the building catch fire, under conditions which would have no serious effect on beams made of certain hard woods such as Australian Karri and British Oak: in situations exposed to the sea air the utility of cast iron fencing posts is destroyed by corrosion in a much shorter time than is that of properly treated timber by rot.

Timber requirements must be separately considered in relation to *Softwoods* and *Hardwoods*. These terms are commonly applied to the timber of coniferous and broad-leaved trees respectively. Though universally accepted, the classification is inaccurate since the timber of many broad-leaved species (*e.g.*, poplar and lime) is much softer than that of many coniferous species (*e.g.*, Larch and Pitch Pine). Generally speaking, the hardwoods supply timbers which are more ornamental, strong and durable, whilst the soft woods provide timbers for general utility purposes; there are, however, several exceptions. The consumption of softwoods is much greater than that of hardwoods, partly because of the great demand for purposes for which the former are peculiarly suitable,* and partly because they are generally cheaper. There are, however, many purposes for which softwoods are at present used on account of their cheapness (*e.g.*, for flooring, furniture, etc.) for which hardwoods would be preferred on other grounds, and, should there arise a shortage of softwoods, owing to the depletion of the restricted area of virgin forests from which the present supply is largely derived, hardwoods would be substituted. Increased prosperity may also be expected to increase the comparative demand for hardwoods. The economic reasons for the preference for softwoods are as follows :—

(a) The simpler structure of softwood timber makes it easier to work, so that the cost of labour from the felling of the tree to the finished article will be less than in the case of hardwoods.

(b) Softwood is generally lighter and therefore less expensive to transport than hardwood.

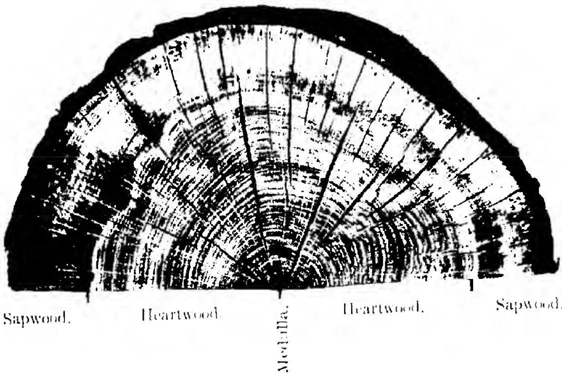
(c) Softwood is generally more easily and quickly seasoned (*See:* Section 3) than hardwood.

(d) Though the supplies of hardwoods in the world are enormously greater than the supplies of softwoods, the latter are much more accessible, particularly to cheap sea transport.

The tendency of coniferous forests to form pure crops also makes them more economical to exploit than hardwood forests. The chief reserves of the latter are tropical forests which usually

*Wood pulp is obtained almost exclusively from soft woods, chiefly spruce.

A



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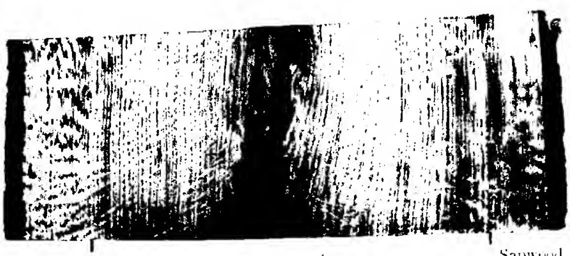

Sections of an Oak-tree.
A: Horizontal Section.
B: Vertical Section through Centre.

See opposite page.

PLATE III A & B.

To face page 171

contain a large number of species, many of which may be of little value.

2. The Structure of Timber in Relation to its Use and Durability

In order that he may grow timber of the best quality and hand it over to the user in the best condition, it is necessary for the forester to have some knowledge of its structure. Timbers, like all other organic substances, have a cellular structure and the cells vary in form according to the functions which they perform and the species of tree. The details of the cellular structure can only be seen under the microscope, but the varying form of the cells gives rise to features, some of which are visible to the naked eye. Thus, on a cross section of the oak (*Plate* III A opposite) the following features are visible:—A central medulla or pith, surrounding which is a broad zone of dark coloured timber, the heartwood, which has ceased to take an active part in the life of the tree; between the heartwood and the bark is the sapwood, a zone of lighter coloured wood* and the living part of the stem which conveys and stores the food material; a prominent feature of the section is a number of concentric rings, each formed by one year's growth, which arises from a difference in the cell structure of the wood formed in the spring and summer respectively. A closer observation will show a number of light coloured lines running radially from the bark towards the central pith (they are invisible to the naked eye in conifers and many broad-leaved trees); these are known as medullary rays, from the fact that those first formed originate from the medulla; they are more clearly seen if the timber is cleft radially through the medulla (*Plate* III B opposite), when they appear as glossy flakes and provide the feature known as silver grain on wainscot oak. Whereas most of the cells in a tree stem are elongated vertically, those in the medullary rays are elongated horizontally and they therefore form a connecting tissue between the different layers of wood and serve both nutritional and mechanical purposes. The above features are of practical importance from the point of view of utilisation. The heartwood of oak (and that of most other timbers) is harder and more durable than the sapwood, and the proportion of heartwood increases with age. The quality of the wood varies with the width and regularity of the annual rings, *i.e.*, with the rate of growth in diameter. Generally speaking, slow grown timber is of better quality than fast grown timber; but in the case of oak, and some other species of similar

*In many species of trees there is no colour distinction between the heartwood and sapwood.

structure such as the elm and Spanish chestnut, the faster grown timber is harder and stronger, though the slow grown timber, being easier to work, is preferred for many purposes. Rate of growth can, to a considerable extent, be controlled by the use of proper silvicultural methods. Timber can be split most easily along the medullary rays, and planks sawn as near as possible parallel to the medullary rays shrink less in drying and are therefore much less liable to split and warp. As regards oak and other timbers with broad medullary rays, timber sawn in this manner is also more ornamental. The structure of branches is the same as that of the stem; but, as they originate from the central medulla and traverse the stem, they form a break in the regularity of the grain in the latter and lower its quality. When the stem is sawn up they are visible as knots. If the branches fall early in the life of the tree, the stem grows over the stump, and, in the course of a few years, the normal direction of the fibres in the stem is renewed, so that the effect of the knot is confined to the central core of the tree. By growing trees sufficiently close so that the branches die and break off at an early date, the forester can ensure that the bulk of the timber is free from knots; in some cases the branches are removed from selected trees (*See:* Pruning, p. 94).

The structure of timber of different species shows considerable variation, but there are certain characteristics common to all species of broad-leaved and coniferous trees respectively. The latter have less variation in the form of their cells and the timber is consequently of simpler structure; also the timbers of these two classes contain substances of a different chemical constitution, resulting in a difference in the secondary products which can be obtained from them.

3. The Seasoning of Timber

The timber of a tree contains water in the cells and cell walls and, in the living cells of the sapwood, substances providing food material for the tree and capable of being used for the same purpose by other vegetable and animal organisms. Seasoning means a treatment of the timber so as to stabilise the moisture contents and remove the food material or alter its constitution.

Stabilisation of Moisture Content. — A tree begins to part with its moisture as soon as it is felled, " in drying the free water within the cells passes through the cell walls—most freely in a longitudinal direction—until the cells are empty, whilst the cell walls are still saturated. When all the free water has been removed the cell walls begin to yield up their moisture " (J. B. Wagner, *Seasoning of Woods*). When the cell walls are once dry they become much more impermeable to water, and consequently

dried timber is less liable than green timber to absorb and part with water in changing atmospheric conditions. Since changes in the water content involve shrinkage and swelling and, since these changes are not uniform throughout the timber, undried timber is liable to split and warp (change its shape), whereas dried timber attains a considerable degree of stability. There always remains, however, some capacity, varying in different species, for absorbing and parting with water and the degree to which timber should be dried before use depends, therefore, on the conditions under which it will be used. If the drying process is unduly rapid the cell walls in the outer layers of the timber will part with their water, whilst the cells in the inner layers are still saturated. The former, having then become impermeable, the water in the latter cannot escape and the shrinkage of the outer layers will cause the timber to split. This consideration results in autumn or winter felling being preferred to spring and summer felling in temperate climates. Hardwoods take longer to dry and are more liable to split and warp in the process than softwoods. Another object of drying is to reduce the weight and therefore the cost of transport. Timber is dried either in the open air or in kilns. Until recent years kiln dried timber had a bad name owing to the drying processes not being properly understood. As a result of modern research, however, the technique has been greatly improved and kiln drying enables the process to be controlled according to individual requirements to a degree which is impossible with natural drying. Kiln drying is a matter of hours instead of months or even years, as in the case of natural drying.

*Removal of Food Material.**—The sapwood contains a considerable part of the reserve food material of the tree chiefly in the form of starch, sugar and fat. Fungi and insects are also capable of using such material as food; consequently, if it is present in appreciable quantity when the timber comes into use, the latter is liable to invasion and damage by such organisms. If conditions are provided so that the sapwood cells remain alive for a time after the tree is felled, these food materials will become exhausted, since there is no other source of nourishment for these cells. Such conditions may be provided by keeping the timber in log with the bark on and the ends protected, so as to delay drying out until the reserve materials have been used up; another method is keeping the logs under water. Breaking up the log and kiln drying kill the sapwood cells and the food materials cannot then be removed from the timber.

*Based on a paper, "The fate of the reserve materials in the felled tree," read by Dr. S. E. Wilson at the British Association Meeting at Norwich, September, 1935.

Though much has been learnt of recent years, our knowledge of what takes place in seasoning timber is far from complete. There may be changes in the chemical character of its constituents other than those referred to above. It is considered that the log seasoning referred to is mainly required in the case of hardwoods, the sapwood of which contains, in the resting season, a large accumulation of starch, which forms the food material of the Lyctus beetle, a pest which causes serious loss in timber depots. Log seasoning is, however, impracticable with some species, for example, the Beech and Sycamore, the timber of which discolours and loses its value if it is not sawn up at once.

4. The Durability and Preservation of Timber

Timber of different species varies very greatly in its durability and heartwood is generally more durable than sapwood. Some hardwoods are very resistant to decay, but are preferred by wood-destroying beetles to softwoods. Timber is liable to be destroyed by animal agencies such as beetles, marine borers, white ants, etc.; decay is caused by fungi and bacteria. These organisms find their source of nutriment either in the timber itself or in the substances (water, starch, sugar, etc.) which it contains. Damage may occur before the timber leaves the forest and the conditions under which timber is felled and extracted influence its future durability. The felling season is the first consideration. In temperate climates the organisms which attack timber are less active in the winter and the food material in the timber is then in a less assimilable form. For this and other reasons autumn felling is usually desirable. After felling, the timber must not be left a long time lying about in damp ill-ventilated situations before being brought into use.

Subsequently the life of the timber will depend on the conditions under which it is used and on the employment of protective treatments which exclude destructive agencies. We may consider the matter under the headings Environment, Surface Protection and Impregnation.

Environment.—Fungi and bacteria require air, moisture and a suitable temperature for their existence. An excess of moisture resulting in a deficiency of air, a condition provided when timber is kept under water, inhibits their life, and an excess of air, a condition provided by good ventilation, makes the attack of these organisms less liable to occur and in some cases excludes it altogether. Thus the dry rot fungus, which is mainly responsible for the rotting of timber used in buildings, does not occur in buildings which are well ventilated.

Surface Protection.—The surface of timber may be coated with paint or other substances to exclude destructive organisms. The permanency of the protection depends on the permanency of the protective coat, which is ineffective if cracks develop. Coating the surface of *unseasoned* timber merely accelerates decay; the cracks which will develop will give access to fungi and bacteria to the interior of the wood, the moist condition of which will be very favourable to their development.

Impregnation.—The process consists in treating the sapwood of timber with a substance which destroys its food value or is actually toxic to the vegetable and animal organisms which might attack it. The timber may be steeped in the preservative, or the latter may be forced into the cells by pressure processes. The latter method is more efficient and may result, in some species, in the complete impregnation of the sapwood, which will, if a suitable preservative has been used, be rendered as durable as the heartwood. Various substances are used, but, in Great Britain, creosote, owing to its reliability and cheapness, is most favoured for outdoor purposes. Preservative treatments are especially applicable to timber used in the open and in contact with the ground, where the conditions favour the growth of those fungi and bacteria which cause various forms of rot. One great advantage of preservative treatment is that it enables the less durable and cheaper timbers to be substituted, without loss of efficiency, for the more durable and more expensive ones; for example, creosoted pine or beech posts may replace those of oak or larch.

5. The Felling and Rough Conversion of Timber

Procedures are influenced by

(a) The value for the timber felled.

(b) The danger of damaging trees left standing or young growth.

(c) The demands of economic working.

The first point to be considered will be the season at which to fell. Since forestry operations seldom provide employment throughout the year for all the labour they require, it is desirable that the demands of forestry and agriculture for the services of the local workers should in so far as possible be complementary. From this point of view, therefore, felling should begin at the season when field operations are slackening, namely, in the autumn. In temperate climates, considerations relating to the quality of the timber also indicate autumn and winter felling as has been shown in sections 3 and 4; and finally, where some trees are left standing or regeneration is required, the damage

caused by felling and extraction will be least, if these are completed in the resting season. Where both broad-leaved trees and conifers have to be felled, the former will be felled first, as this timber takes longer to season. Where, however, the coppice with standards system is in operation, coppice must be felled before the standards; and, in this case, danger of damage by frost to the stools may necessitate postponing fellings until early in the year.

The direction in which a tree falls is controlled by the manner of placing the cuts and should be such that the tree will do the least damage to itself and to valuable standing growth. A tree felled down hill, or across a mound or another fallen tree, may have its value destroyed by splintering.

The forester is usually concerned only with rough conversion in the forest, such as the removal of branches and the division of the logs to facilitate transportation. Where, however, small wood, such as fuel, pit props, poles, etc., is being extracted, he will convert it into pieces of suitable dimensions and stack these ready for removal. Where extraction is very difficult it may be necessary to saw up the logs, before removal, either by hand saws or in a small mill. In such circumstances some knowledge of the most economic methods of breaking up a log, the use of saws of different types and the application of power will be required; but the management of a large saw mill is a specialised occupation requiring long study and experience, and does not come within the scope of an ordinary forester's duties.

6. The Transport of Timber

Timber is bulky, awkward to handle, and of relatively small value, and forests generally occupy the roughest and least accessible localities in any country; consequently the problem of transport has a very important bearing on forest management. In a highly developed country, like Great Briatin, with an extensive system of roads, maintained at the public expense, the problem is seldom one of primary importance. A few feeder roads, joining up to the nearest public road, will enable wheeled transport to be used direct from the forest to the market or to a railway. The owner will thus incur little capital expenditure and will be able to distribute his fellings without much regard to the transport question. The situation is quite different where the owner has to provide his own transport ways to a distant market, or, even for a short distance, in mountainous counties. The capital expenditure on a transport way may then become the most important economic factor to be considered and may necessitate a concentration of several years fellings in one place, so as to

recover quickly the capital expense incurred and reduce interest charges. The transport problem may therefore be one which has to be considered before all others and may preclude the working of the forest in the manner most desirable from silvicultural and other points of view.

Many methods are used for the extraction and carriage of timber, and, in the less advanced countries, forest engineering is an important branch of study for the forester. The following is a summary of the methods in use:—

(1) Dragging along the ground either by animals or mechanical power. Confined to moving logs for short distances from the felling area to a road, tramway or floating stream. There is a modification of this system, much used in N. America, where the log is lifted partly or wholly off the ground on an overhead wire rope which can be moved from place to place and joins up with an engine at the terminal of a temporary forest tramway.
(2) Carriage of small timber and fuel by men or pack animals. Very uneconomical, but used in some backward countries, chiefly in mountainous districts.
(3) By wheeled transport on roads. An economical system for short distances.
(4) By tramways. More economical than special roads for long distances, particularly in hilly country.
(5) Caterpillar traction. Since the tractor lays its own track, this is a very suitable method where fellings are scattered and the country is not too rough for the tractor.
(6) Overhead wire ropeways. The capital cost is relatively high, but the system may be very economical in rough and mountainous country owing to the saving in distance compared with a road or a tramway.
(7) Sledges. These are usually confined to down gradients in mountainous country and run on timber tracks or snow.
(8) Timber slides, dry or wet. Confined to down gradients.
(9) Rolling roads. For rolling logs; confined to down gradients.
(10) Floating. By individual pieces in small streams, or in rafts in rivers.

7. Marketing

Timber is disposed of either standing, or after felling and partial conversion, or after felling, partial conversion and removal from the forest with perhaps further conversion in a saw mill. Each method has its respective advantages and disadvantages depending on circumstances. When timber is sold standing it is generally only the big timber merchants who are interested in its purchase. Such persons are seldom dealers in the smaller classes of timber and fuel; consequently, where such produce is of value, the owner will usually do better by felling his timber and dividing it into suitable sale lots according to the different classes. Moreover, if there is a suspicion as to the soundness of the trees (*e.g.*, of heart-rot in old trees), then

better prices are obtained if the trees are felled so that they can be properly inspected. One advantage of selling timber standing is that, if an adequate price cannot be obtained, the trees will remain growing, whereas when once cut the material must be disposed of. Removal of the timber from the forest to a sale depot is seldom worth while, unless it is for the purpose of further conversion in a mill before sale; but this practice may be necessary in the case of inaccessible areas where the owner provides his own transport ways. Timber may be sold by auction, by calling for tenders, or by private bargaining. In order to obtain good prices the following are the requisites:—

(a) Regular supplies.
(b) Division into suitable lots properly displayed so that defects are not concealed.
(c) Skilful advertisement and adequate notice of sales.
(d) Correct measurement.

The qualities which make for efficiency in production are very different from those which make for efficiency in marketing, and it is a common experience that both agriculturalists and foresters often fail in the latter branch of their profession. The forester is generally well advised not to endeavour to dispense with the middle-man, where an experienced and efficient body of timber traders is in existence; but, whether he deals with the middle-man or direct with the consumer, knowledge of business methods and market conditions, and ability to conduct personal negotiations, are essential for the profitable disposal of produce. The question of markets has, of course, to be considered before laying down a plan of management. Market conditions must, however, be kept under constant review, lest changing demands should find the management unprepared with suitable material or with a quantity of unsaleable material on its hands.

PART IV

FOREST MANAGEMENT

CHAPTER VIII

GENERAL CONSIDERATIONS

1. OBJECTS OF MANAGEMENT

As has been stated in the Introduction to this book, management co-ordinates the different branches of forestry with the object of utilising the forest land so as to meet in the highest possible degree the wishes of the owner. Thus, forests may be maintained for several purposes such as

Protection of water catchment areas.
Beautifying the landscape.
Providing recreation.
Giving shelter to agricultural land.
Prevention of erosion.
Fixing sand dunes.
Harbouring game.

The above may be regarded as indirect purposes requiring a special form of management. More generally forests are maintained for the sake of the marketable products which they yield. The marketable product may be a minor* one such as resin, requiring again a special form of management; but the majority of forests are maintained for the purpose of producing a revenue from the soil by wood crops and in the following chapters the subject of forest management is dealt with mainly from this point of view.

2. INFLUENCE OF BIONOMIC CONDITIONS

The basis of successful forest management is a correct appreciation of the ecological characteristics (*See:* p. 38, Trees and their Environment) of the localities of which the forest area is composed. The factors which determine the ecological character of a locality have been dealt with under Silviculture and reference

* Major and Minor Forest Produce see p. 63.

has been made (p. 44) to the natural balance of forces which will, in the absence of outside interference, result in what is called a climax type. A complete knowledge of the ecological conditions will save the forester from the error of aiming at a type of forest incompatible with these conditions and will ensure that the disturbance of natural conditions, which forestry necessarily involves, is of such a nature as to produce or maintain the chosen type. This type may or may not be the natural climax type for the locality and climate. For management purposes a knowledge of the species most suitable for the locality and the best silvicultural treatment may not be sufficient. A knowledge of the range of species that it is possible to grow and the extent to which, any departure from the optimum silvicultural treatment, is compatible with the continued maintenance of forest, may also be required. This necessity to appreciate what may be called the limits of flexibility in silvicultural treatment arises from the fact that economic considerations may, as explained in the next section, prohibit the adoption of the simplest solution of the silvicultural problem.

The statement that forest practice should be based on a complete knowledge of the ecological character of the forest area to be managed, represents a counsel of perfection. Until recent years silviculture was mainly empirical and the highly efficient methods employed in Western Europe were evolved by intelligent experiment with little or no scientific investigation into ecological conditions. The limited number of species employed, and the fact that the existing forests generally represented a near approach to climax types for the localities, lent success to such methods. Nevertheless, the introduction of the best methods was a lengthy process which is probably not yet concluded. Modern forestry hopes, through a study of the biological characters of sites and the requirements of different tree species, to establish a connection between the two which will make a more rapid advance possible. The large number of species and the complex conditions in the tropical and sub-tropical parts of the British Empire, and the economic necessity for growing exotics in such countries as Great Britain, New Zealand, South Africa, etc., provide particularly unfavourable conditions for reliance on purely empirical methods.

The method of regenerating the crop, whether by natural or artificial means, and the technique employed exercise a profound influence on the management of the forest, as is shown in the next chapter (Section 4). The choice of method is affected by economic considerations, but, in the first instance, it is the bionomic conditions which govern the possibility of creating a new crop through the agency of the seed from the old one and

influence the ease with which the operation may be carried out. Generally it may be said that conditions which are very favourable for vegetative growth make the natural regeneration of a selected species difficult, owing to excessive competition of other species. Natural regeneration is usually simplest where the selected species is a hardy one growing under conditions, such as a poor soil and a comparatively rigorous climate, which exclude competitors. A very rigorous climate, however, makes natural regeneration a slow process by reducing the quantity of seed produced. Where a forest of mixed species is to be maintained, replacement by natural regeneration is generally difficult; but, if the species chosen are complementary to one another in their requirements, excellent results may be obtained in such cases by a skilful silvicultural technique. A forest which is not a climax type for the locality may be very difficult to maintain by natural regeneration. On the other hand, a climax type does not necessarily present a simple problem in this respect. Such a type may have been established by long and complicated natural processes, and regeneration fellings introduce an interference with these processes which may produce a result different from that intended.

3. INFLUENCE OF ECONOMIC CONDITIONS ON MANAGEMENT

Ideally, forest land, like agricultural land, should be so managed as to give the maximum permanent productivity. This is sound from the bionomic point of view, but the matter has also to be considered from the economic one, and ideal bionomic management may only be possible where all classes of forest products command a high price in relation to labour and other costs. For example, in Western Europe, owing to the density of the population in the neighbourhood of forest areas, the latter are well provided with roads, and the small material, forming an inevitable part of the yield under any system of management, can be sold for good prices, so that there are no economic considerations which restrict the silvicultural systems and methods of management employed. Public transport facilities and complete utilisation make scattered fellings and small units practicable, if it is desirable, from the silvicultural point of view, to employ them. It is under such conditions that the finest examples of ideal forest management are to be found. On the West coast of North America, on the other hand, where the main demand is for timber of large dimensions for export purposes and where forest produce has to bear the capital cost of its own transport facilities, fellings must be concentrated, and those silvicultural systems

which require dispersed fellings and the removal of small material become impossible. Under such conditions the pressure of economic considerations may be so great as to make it difficult to enforce the first principle of forest management, which is to ensure the permanent existence of the forest. Under primitive conditions the demand on a forest may consist merely of material to provide for the domestic and agricultural requirements of the population surrounding it. In such cases, though the total demand may be considerably less than the forest is capable of supplying in perpetuity, yet difficulties may arise, owing to the concentration of the demand, for building timber, grazing, lopping for fodder, etc., on the outskirts of the forest. Perhaps the most difficult circumstances with which management is faced are such as the above, when advancing civilisation and increasing prosperity result in greater demands for timber and a large increase in flocks and herds, whilst the population are still attached to their primitive methods of agriculture and depend on such grazing as the forest provides. Owing to the comparatively long intervals separating cause and effect in forests, an uncultured agricultural and pastoral population is generally incapable of appreciating the fact that a forest does not provide a natural supply of material for unrestricted and unlimited exploitation. Forestry and agriculture share the fruitfulness of the soil and an inefficient system of agriculture may make forest management impossible.

The fact that *softwoods* derived from coniferous trees are in far greater demand than *hardwoods* derived from broad-leaved trees exercises a profound influence on forest management in many parts of the world. In countries such as Great Britain and some of the British dominions of the southern hemisphere, where suitable indigenous conifers are lacking, it is natural that forest management should, in the first instance, direct its attention to the introduction of exotic conifers by means of plantations. Many of these experiments will doubtless prove successful and profitable, though it is probable that few localities are capable of supporting a *succession* of crops of pure conifers grown on short rotations.

CHAPTER IX

THE REGULATION OF THE YIELD

1. GENERAL

(a) The Meaning of Yield-regulation and Why it is Required

For the purposes of this chapter the yield may be defined as the volume of major produce (*i.e.*, wood) harvested in a forest worked under economic management. It is the income in terms of produce. Every year the growth of the trees adds to the volume of wood in the forest. The addition is known as the increment. If a volume of wood equal to the increment is cut at the end of the growing season, the original volume of the forest remains. If more is cut, the volume of the forest diminishes and, if the excessive cutting continues, the forest will eventually disappear. On the other hand, if less than the increment is removed, the volume of the forest increases and it will contain a steadily increasing proportion of older and larger trees. After a certain age trees cease to put on an appreciable growth and, if no fellings are made, the time will come when the volume of new growth on the younger trees is offset by the death of old trees, so that there is no net increment. In the case of overcutting the proprietor is, in effect, treating as income what is, in part, really capital; when he undercuts, he is accumulating as capital part of the annual income. The importance of regulating the cut so as to maintain the correct amount of growing stock or capital has been dealt with under forest valuation (Chapter V: Sections 2, 3 and 4).

In the forest the increment is added to all the trees and cannot be separated from them. The yield is in the form of whole trees, and its regulation requires, in the first instance, a decision as to the age or size at which individual trees or woods shall be considered mature. Such mature trees or woods provide the *final* yield, which is the most important part of the yield and the principal factor to be regulated. In order to perpetuate the forest it is necessary that trees or woods cut in the final yield

shall be replaced by young seedlings or plants; thus the exploitation of mature trees must be accompanied or followed by regeneration. There will also be an *intermediate* yield obtained from thinnings. Primarily these are carried out in the interest of the final crop and management does not generally treat the yield from this source as an economic aim. There are, however, exceptions to this rule, and the yield, if saleable, must affect the capital value of the forest (*See:* Valuation). There may also be an *accidental* yield as a result of storms, fire, insect or fungus attacks, etc.; this necessarily reduces the yields under other heads and may seriously upset the arrangements made for yield regulation.

(b) The Rotation

It is clear that the first factor affecting yield will be the length of time allowed to elapse between the formation of a crop and its final harvesting. This period is called the rotation. In accordance with the considerations which affect its choice, foresters distinguish different kinds of rotation. The *silvicultural rotation* is the rotation with which natural regeneration can most efficiently be carried out. The age of the crop affects both the production of fertile seed and the suitability of the soil covering for the germination and growth of seedlings; but, since the period of healthy seed production normally covers a considerable portion of the life of a tree and, since both seed production and the character of the seed bed can be influenced by the silvicultural treatment of the crop, economic considerations can generally be given fairly free play in the case of a high forest to be regenerated by seed from the old crop. In the case of regeneration by coppice shoots, rotations must be comparatively short, since most trees lose their capacity for producing healthy coppice shoots fairly early in life. In considering the rotation from the economic point of view, first place will be given to the technical requirements arising out of the objects of management, and the rotation, under which the forest yields the most suitable material for a certain purpose or results in the production of timber of a size which permits the most economical conversion, is known as the *technical rotation*. There may be a market for different classes of produce requiring different technical rotations and, if the necessary data are available, a financial test may be applied (*See:* Valuation) to determine which class of produce and technical rotation is most profitable. Where the principal demand is for sawn timber of varying dimensions, it is the case that the greater, within reason, the diameter of the logs the more economical the conversion. This advantage may be counterbalanced by the rapidly increasing cost, owing to the accumulat-

ing compound interest charges, of growing trees of large diameters. In a virgin forest the largest trees are generally of much greater age and size than is compatible with economic production. The first requirement of scientific management in such forests is therefore the introduction of a rotation which greatly reduces the permitted life of the trees. In these circumstances the absence of data, the uncertainty of forecasts of future demands and the necessity to avoid flooding the market require that such reduction shall be gradual. In the first instance, therefore, it is common practice to adopt the rotation of the *maximum volume production,* which is coincident with the rotation at which the M.A.I. culminates (*See:* Mensuration, p. 163), or the rotation of the *maximum net income* (*See:* Valuation, p. 146), which, in the absence of any price increment after the M.A.I. culminates, is the same as the former. These rotations are generally high compared with technical and financial rotations. Though, as has been shown under Valuation, they are in theory unsound, yet they have an economic basis and are founded on more easily determined and reliable data than financial rotations. The investigations into rates of growth necessary for fixing the rotation are dealt with under Mensuration. The rotations actually applied in forestry vary very greatly in length. For coppice they are generally between 10 and 30 years; for high forest they are seldom below 40 or 50 years, and a rotation of 400 years is actually applied in certain German oak forests. Rotations of more than 150 years are, however, rare. Only under a clear felling system is the rotation an exact period. Under shelter wood systems of natural regeneration the rotation represents only the approximate age which trees are allowed to attain before they are felled.

2. MANAGEMENT FOR AN INTERMITTENT YIELD

If an even-aged wood is treated individually and not as a unit of a community, there will be, during each rotation, intermittent yields from thinning operations, carried out with the object of obtaining the maximum amount of the most suitable material from the crop when mature, and, eventually, the final yield from the wood. If several woods, of varying ages, on an estate are treated in this manner, the estate may receive an annual income from its woodland resources; but, except accidentally, there will be no regularity in such income. There is in this case no regulation of the yield beyond that provided by fixing the rotation, and the exercise of the most difficult function of forest management, the regulation of net income, is avoided. Management for an intermittent yield has the further advantage

that the treatment of each wood is affected by its own requirements (and the owner's necessities) alone and not by the requirements of an organised collection of woods.

3. MANAGEMENT FOR A SUSTAINED YIELD

(a) Object and Foundations of Management for a Sustained Yield

In large commercial forests the following considerations generally render it undesirable to deal with the individual woods in the manner described in the last section.

(i) It is desirable to equalise the annual incomes.
(ii) Regular employment must be provided in order to ensure an adequate supply of trained labour.
(iii) Regular supplies must be provided in order to retain a market.
(iv) Forest produce is bulky and heavy and requires the provision of special transport. Such transport will be unduly expensive if only used intermittently.
(v) The permanent trained establishment must be continuously employed.

In order that the above advantages may be obtained, the forest must be treated in such a way as to give approximately equal annual yields. Each wood will no longer be an independent organism, subject to purely individualistic treatment; it will be a unit in a community of woods, *i.e.*, the forest, and its treatment will be such as to fit it to take its proper place in this community. It is the principal function of forest management—a function which distinguishes it from purely woodland or estate management—to provide, through the regulation of the yield, that organised collection of woods on which the maintenance of a regular yield depends. In the case of a forest, in which either woods or trees representing all age gradations in the rotation are present, an annual income may be obtained by felling each year the oldest age gradation. Only, however, where all the age gradations are represented in the proper proportion will such fellings result in an equalised annual income. Where the age gradations are so represented the series which they form is called a *Normal Series of Age Gradations,* and the forest so constituted is called a *Normal Forest.* The normal forest is an ideal which it is necessary for the forester, managing a forest for a sustained yield, always to have before his eyes. In theory it is easily conceived, particularly in its simplest form where the forest is formed of a series of even-aged woods established by clear-felling. It is, however, a state which never exists in nature and which—except occasionally under clear felling with a short rotation—cannot be maintained in practice. Moreover, where the age gradations are mixed, as they always are when a natural

forest first comes under scientific management, and as they are also under the most commonly employed silvicultural systems, it is difficult to determine the extent to which the actual forest differs from the normal.

(b) Basis of Yield Calculation

(i) *The Normal Forest.*—The basis of yield calculation will be more easily understood if we deal in the first instance with the

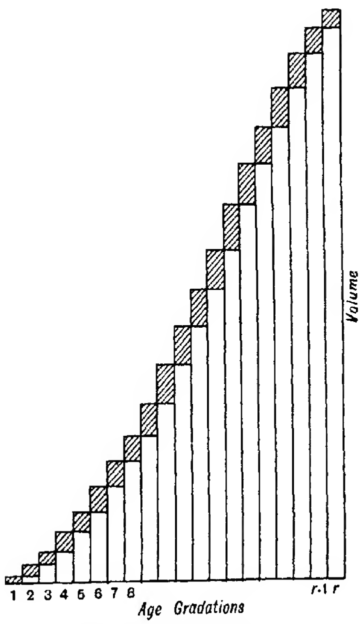

Fig. 10. Normal Age Gradations forming a "Normal" Forest.

theoretical normal forest. A normal forest may be illustrated by a diagram as in *Fig.* 10, where the several rectangles represent the volumes contained in each age gradation from one year old up to rotation age. This diagrammatic illustration may be used whether the age gradations occupy separate areas or whether they are to a greater or less degree intermixed on the same area. In the normal forest the annual final yield is represented by the

volume of the oldest age gradation, which is equivalent to the sum of the current annual increments of all the age gradations (C.A.I.), and we may express the yield in one or the other of these terms. Further, there will be certain relationships between the growing stock (G.S.)—which is the sum of the volumes of all the age gradations—the volume of the oldest age gradation and the C.A.I.; though these relationships will be different for every species, locality, silvicultural treatment and rotation. We may, therefore, measure, either the volume of the oldest age gradation, the C.A.I. or the G.S., in order to determine the yield; the last measurement will not, however, suffice, unless we have already determined the proportion of the G.S. to the other factors for the conditions with which we are dealing.* The execution of the necessary thinning operations in the immature woods provides also equal annual intermediate yields, since it may be assumed that woods of the same age are similar and require the same treatment. It will be seen, therefore, that the theory of the separation of the income and capital and the equalisation of the yields in a normal forest presents no difficulty. The above facts provide the basis of every method of calculating the yield where sustained yield is the object of management.

(ii) *The Real Forest.*—Actual forests are, as has already been stated, generally abnormal. A type of such forest is illustrated in *Fig.* 11, and it is clear that here the above stated relationships between the C.A.I., the oldest age gradation and G.S. are non-existent. If then it is accepted that the object is to lead over the forest to a normal condition, we cannot separate the annual increment or the oldest age gradation from G.S. and say, *this is the income and yield to be cut and that is the capital to conserved.* Where G.S. is in excess of the normal, some of it must be removed annually in addition to the increment or the oldest age gradation, and, where it is in deficit, some of the annual increment must be conserved in order to increase it. A careful analysis of the actual distribution of the age gradations will indicate the procedure required to bring about their more normal representation, and the period within which normality may be aimed at. During the period of readjustment annual yields may be equalised at a figure above or below the normal increment. In practice the advance towards the normal is generally made by steps, the annual yields being calculated and equalised for a short period only. At the end of such a period

* A much used formula in forestry assumes that the steps in *Fig.* 10 (representing C.A.I.) are all equal, in which case the total C.A.I., the volume of the oldest age gradation and the quotient given by $\frac{2 \text{ G.S.}}{\text{Rotation}}$ are all equal and represent the annual yield. Whilst the assumption is incorrect the corollary based on it is true for a certain rotation.

the position is again reviewed and the yield re-calculated. If the management is successful, the adjustments required in the G.S. will be less at each revision. Setbacks may, however, occur from several causes, such as an incorrect estimate of the yield, or damage by wind, fire, insects, etc., or failure to get regeneration owing to faulty silvicultural technique, failure of seed years, drought, etc. The illustration of the forest by a

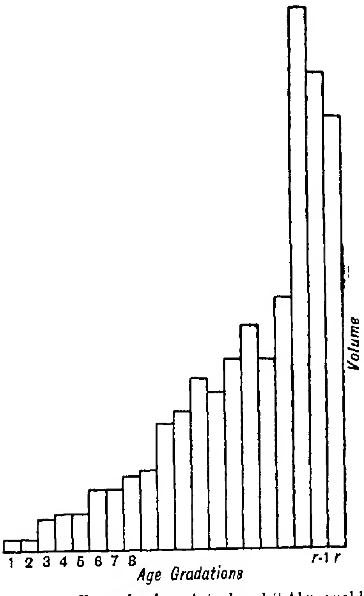

FIG. 11. Example of an Actual and "Abnormal" Forest.

diagram in a simple form for the purpose of explanation must not be allowed to obscure either the fact that the forester is not restricted to the oldest age gradation for the final yield, nor, on the other hand, the fact that silvicultural and market considerations prohibit his felling the excess G.S.—or conserving it where it is deficient—in each and every age gradation. Finally, it must be remembered that the age gradations are not necessarily separated as they are in the diagram. The practical methods by which the yield is regulated under different silvicultural systems is dealt with in Section 4.

(c) Division into Compartments

A division of the forest into compartments is necessary for the purpose of locating and describing the crops and organising the management. These compartments are permanent units; they vary in size according to the intensity of management. They must be easily identifiable on the ground and, where natural boundaries are not available, they must be given artificial ones, such as, lines cleared of tree growth, or boundary pillars. They are designated by numbers.

(d) Felling Series

A felling series is the practical counterpart of the theoretical normal series of age gradations. The forest may constitute one felling series or it may be divided into several; the decision depends on the size of the forest and convenience in organisation. Each felling series will be managed with the object of developing in it the character of a normal forest and it is, therefore, a management unit for the regulation and calculation of the yield.

(e) Division into Cutting Sections

A cutting section is a subdivision of a felling series formed with the object of regulating cuttings in some special form. Thus, under the clear cutting system in high forest, the danger of fire and insect damage is greatly increased when adjoining areas are cleared and planted annually. To lessen such danger the felling series may be divided into separate parts (cutting sections) and the annual coupe felled in each part in turn so that in any place adjoining crops differ in age by as many years as there are parts.

4. EFFECT OF SILVICULTURAL SYSTEM ON MANAGEMENT FOR A SUSTAINED YIELD

It has been shown (Section 3 a & b) that management aims at an equalisation of the annual volume yields. It is, however, easier to measure the area occupied by a crop than to measure the crop itself and, consequently, foresters prefer, wherever possible, to make area rather than volume the basis of yield regulation. Regulation by area can only be applied effectively under those silvicultural systems which result in more or less even-aged crops. As has been shown under the heading *Silvicultural Systems* (p. 99), woods most even in age are produced by clear felling with artificial (or coppice) regeneration, which results in considerable areas being occupied by only one age gradation; whereas woods most uneven in age are produced by the selection system, where all the age gradations are mixed.

Other shelter wood systems of natural regeneration may result in even or uneven-aged woods according to the size of the regeneration area and the length of time elapsing between the first and last regeneration felling on the same. In some uneven-aged forests regulation of the yield by volume is inconvenient or impossible and the yield is defined as a number of trees of or above a certain size. The following is a brief account of how the yield is regulated under the different silvicultural systems.

(a) Regulation of the Yield under Clear Felling

(i) *Clear Felling in High Forest.*—The yield is regulated by area, the area of the annual coupe being obtained by dividing the number of acres in the felling series by the number of years in the rotation. Thus, if the area of the series is 500 acres and the rotation is 50 years, the normal annual coupe will be 10 acres. Thinnings will also be regulated by area, the actual year in which each wood will be thinned being generally laid down in advance. Thus, in this instance, if thinnings are required at the ages of 15, 25, 35 and 45, there will be 10 acres of each of these age gradations to be thinned annually. If there are considerable variations in the quality of the soil, all areas should first be reduced to a common quality class, and the annual coupes will be areas of equi-productivity. If the forest is normal, the annual yields will be equal; and, if it is not normal, by cutting annually the normal coupe, normality will, in theory, be introduced within one rotation, but some woods will have to be cut at above or below rotation age.

If the forest is very abnormal the attempt to establish normality in one rotation may involve too great a sacrifice of immature material and it will be necessary to make the annual coupe more or less than normal, thus delaying the establishment of the normal forest. Where a new forest is being established artificially, the attainment of the normal forest in one rotation may be contra-indicated owing to the undesirability of leaving a large part of the land idle for several years. In many cases this difficulty can be got over by raising catch crops of quick growing species, which will produce marketable material on a short rotation, or by putting the land to temporary agricultural uses.

(ii) *Coppice and Coppice with Standards.* — The yield from coppice is regulated by area in the same manner as under clear felling in high forests. In coppice with standards, the management decides on the maximum size of the standards required and estimates the rotation necessary to produce this size. Since standards are felled in the same year as the coppice, the rotation of the standards must be multiple of the rotation of the coppice.

At each felling of the coppice a number of selected stems are allowed to grow on into standards; this number will be in excess of the number of standards which will be retained up to rotation age, and some of them will be felled at each subsequent felling of the coppice. Thus, in a felling series covering 200 acres, where the rotation of the coppice is 20 years and the rotation for the standards 100 years, the annual yield will be as follows:—

a 10 acre coupe of coppice,

a certain number of standards on the same coupe aged 40, 60, 80 and 100 years.

The number of standards of different size available for felling in each annual coupe will depend on the number of stems originally reserved from the coppice crop and subsequently in the overwood. The number reserved will depend on the relative importance attached to the standards and to the underwood, with the proviso that it must not be so great that the shade of the standards will adversely affect the growth of the underwood. The quality of the standards, *i.e.*, the length of bole free from branches and knots, will be influenced by the length of the rotation of the coppice; but generally the latter is governed by the technical and silvicultural requirements of the coppice itself.

(b) Shelter Wood Systems

(i) *Even-aged and Uneven-aged Woods.*—It has been explained that, where clear felling is adopted, sustained and equal annual yields are obtained by cutting annually the area occupied by the oldest age gradation; *i.e.*, the yield is regulated by area. Where regeneration is carried out under the shelter of an old crop, the latter is usually removed in several operations; and, on the same area, not necessarily — or even usually — in equal quantities at each operation, so that felling over equal areas annually will not result in equal yields. The annual yields must, therefore, be regulated by volume. If, however, the silvicultural system is such that the regeneration fellings proceed regularly over each wood in a comparatively short time, so that at maturity the woods are for all practical purposes even-aged, and homogeneous woods are formed, whose age limits cover consecutive periods throughout the rotation, then, by allotting woods for felling to periods of the rotation, so that each period contains an equal (or equi-productive) area, there will be an area basis for the regulation of the *periodic* yield. If, on the other hand, the silvicultural system of regeneration employed involves a long regeneration period, or a period varying within wide limits, it will not be possible to equalise periodic yields by the allotment of equal areas to periods, and a method of regulating such yields by volume will

be required. It will be seen, therefore, that the yield may be regulated by area and volume combined, or by volume only (*See:* Combined and Volume Systems below). Selection forests, the extreme example of irregular woods, with all age gradations intermingled, present a special case and will be dealt with separately.

(ii) *Combined Method.*—There is a parallel division of the rotation into periods and of the area of the series into periodic blocks. The length of a period should be the approximate length of time which is required completely to regenerate the average wood. Thus, if the area of the series $=1{,}200$ acres, the rotation $=100$ years and the length of a period $=20$ years, there will be $\frac{100}{20}=5$ periodic blocks, each having an area of $1200\times\frac{20}{100}=240$ acres (reduced areas being substituted for real areas if there is more than one quality class). Compartments occupying approximately 240 acres are allotted to each block, the oldest to the first and so on. The annual final yield for the next 20 years is calculated from the volume standing on the first block at the commencement of the operations, and to this must be added the increment which it is estimated will accrue for half the period, *i.e.*, 10 years; the reason for this is that 10 years is the average length of time which will elapse before the crop is felled. The standing volume and increment may be determined from yield tables, or computed from enumerations and volume tables, by the methods which have been explained under mensuration. Intermediate yields will be obtained from thinnings in the blocks not under regeneration; generally a thinning cycle is established, every wood being thinned at fixed intervals and the yield regulated by area. Such is the theory of the method. In practice it is seldom quite so simple, and there are several alternative methods of dealing with the practical difficulties which arise from such causes as failure to complete the regeneration within a block by the end of a period, etc. The tendency is for the blocks to lose their theoretically permanent character—*i.e.*, containing the same compartments in each rotation—and for the current regeneration block to contain an area larger than the normal, owing to the inclusion within it of woods which have already been partially regenerated. The allotment of compartments to blocks other than the first is often omitted. If the forest is abnormal, as will be determined by investigating the areas occupied by the different age classes, the regeneration of equal areas in each period will, if it can be carried out, introduce the normal forest in one rotation. Often, however, this course is impracticable, since it would involve too great a departure from the technical requirements of the management or the silvicultural requirements of the

crop. The method can only be applied to even-aged woods or to uneven-aged woods which are to be converted into even-aged ones.

(iii) *Volume Method.*—This is applied to uneven-aged woods and also occasionally to even-aged woods in place of the more simple method described above. The yield is calculated from the growing stock and/or increment of the whole felling series (*See:* Section 3b). In the case of uneven-aged woods, the degree to which the forest departs from the normal cannot be determined from an investigation into the areas occupied by age classes, as it can in the case of even-aged woods. Consequently, to the difficulty of leading over the forest into a normal state is added the difficulty of determining its present relation to the normal.

Even if the forest is normal, it is not possible to equalise the yield by the simple method of felling each year the trees which have reached rotation age (*See:* Section 3b). In the first place it is not possible to determine the age of trees before they are felled and, in the second place, silvicultural principles do not permit of such an arbitrary method of realising the yield as is involved in felling all, and only, those trees which have reached a certain size. It is possible to determine the number of trees, or the volumes, supplied by the different age classes by enumerating the trees in size classes and establishing the average age of the classes by ring countings on the stumps of felled trees; but there is no general basis for deciding exactly what would be the correct proportions, either by number of trees or volumes, in the age classes of a normal series. It is known that these proportions will vary according to silvicultural treatment, so that no reliable guidance can be obtained by comparing them with the corresponding figures for even-aged woods derived from yield tables. Frequent inventories of the crop by the size classes must be made, the actual increment in relation to the actual distribution of size classes determined, and gradually the fundamental facts for a correct regulation of the yield accumulated (*See:* Section 3b).

The yield having been calculated, any convenient period, usually from 10 to 20 years, for the working plan (*See:* Chapter X) is chosen, and those compartments, in which regeneration fellings are seen to be required during the period, are allotted to a regeneration area from which the prescribed yield will be cut. A sufficient area must be allotted to supply the prescribed yield, but it is not a requisite of the method that the regeneration should be completed within any compartment by the end of the period. If the woods are very uneven-aged, the regeneration area may represent a very large proportion of the series and, in this case, it will include portions where thinnings rather than final

fellings will be required. Thus there may be no separation of intermediate and final yields in uneven-aged woods.

(iv) *The Selection Forest.*—This represents the extreme case of an uneven-aged wood where all the age gradations are mixed on the same area. The yield may be regulated by the number of trees, or by the volume to be removed annually, and will cover both final fellings and thinnings, these usually being carried out in one operation. The best methods of yield regulation involve repeated measurements of the trees by diameter or girth classes. A comparison of these crop inventories and a knowledge of what has been cut will indicate whether or not the management is being successful in introducing a more normal distribution of age classes. A small selection forest may be undivided, that is to say, that each year (for an annual yield) fellings will be carried out over the whole area. In larger forests a felling cycle, the period elapsing between two fellings on the same area, will be constituted, and the felling series will be divided into a corresponding number of cutting sections. Thus, if the felling cycle be 10 years, there will be ten cutting sections, in each of which the calculated annual yield will be cut at ten-year intervals. In comparatively small forests a cutting section and a compartment may be synonymous; in larger forests a cutting section will be a collection of compartments, not necessarily adjoining one another. If fellings are to take place in only one cutting section each year and annual yields are to be equalised, then, in theory, the cutting sections should be equi-productive with exactly similar growing stock. In practice it is often necessary to depart from the exact felling intervals or the exact equalisation of annual yields; though, in the absence of accidents such as heavy windfall, the felling sequence may be adhered to. Where the species grown is suitable for the employment of this system, it gives scope for a high degree of individualistic treatment, from which excellent results may be obtained, if the management is very highly skilled. Likewise, if the management is not so highly skilled, or if it lacks continuity, then the results may be far from satisfactory.

CHAPTER X

THE PREPARATION OF A FOREST WORKING PLAN

1. **Definition.** — A forest working plan is the document which sets forth the aims of the management and the scheme of operations by which it is hoped to attain them.

2. **Purpose of a Working Plan.** — Apart from the general necessity of operating any commercial enterprise in accordance with an intelligent scheme, there is a special necessity in the case of a forest project, owing to the long period separating results from the actions which produce these results, to the continuous nature of the operations required to produce the results, and, in the case of large estates, to the varied nature of the interests involved.

In the case of a very small estate the plan may be a brief and simple one dealing only with the prescriptions for the maintenance of the forest and the regulation of the yield and including a statement of the silvicultural and economic considerations on which these prescriptions are based. In the case of extensive tracts of forest, it is probable that, in addition to problems relating to silviculture and regulation of the yield, others relating to such matters as providing for right holders, fire protection, creation of transport facilities, etc., will have to be dealt with.

3. **Demarcation.** — Before the preparation of the working plan is commenced the forest must be demarcated, mapped and divided into compartments (*See:* p. 190). The compartments are required for locating the different crops and will be given identifying numbers on the map.

4. **Basis of the Working Plan.** — The working plan is based on all information which can be acquired either from records, enquiry or field investigation regarding

Bionomic Information.
- (a) Biological characters of localities and ecological character of vegetation.
- (b) Present condition of crops.
- (c) Past history of crops.

Economic Information.
- (d) Rates of growth, *i.e.*, productivity.
- (e) Distribution of age classes by area or volume for the purpose of comparing the real with the normal forest.
- (f) Markets.
- (g) Labour supply and costs of extraction.

Bionomic Information. — The nature of the investigations under (a) have already been indicated (Chapter VIII, Section 2). Besides the general conditions, those in individual compartments will be considered, when different localities and types of vegetation are present. Since compartments are units of management and, since the management of the whole forest must be based on the treatment applicable to its parts, investigation under (b) and (c) must be for each individual compartment. A *description of compartments* is drawn up containing a statement of all relevant information obtained regarding each compartment, and its suitable treatment indicated; later, when all compartments have been examined, it will be seen to what extent it is necessary to depart from the best treatment of individual units in order to attain the objects of management for the whole area.

Economic Information.—Under (d), unless suitable volume or yield tables are available, it will be necessary to investigate rates of growth for the purpose of fixing the rotation and calculating the yield. Under (e), if the woods are even-aged, the areas occupied by each age class must be determined and their volume obtained from suitable yield tables or by measurement of sample areas. If the woods are uneven-aged, crop inventories must be made. That is to say, the trees are measured in diameter or girth classes (*See:* Mensuration, p. 166) over the whole area, or sample areas, and the volume in each class determined from volume tables or by complete measurement of sample trees. Size classes are converted into age classes from the data collected by investigations into rate of growth.

5. **The Arrangement of the Working Plan.** — No standard form can be prescribed for this document, but the following indicates what is required in the case of an important area of forest. The plan may commence with an Introduction stating the objects which the owner desires to attain and reference to the instructions which the forester making the plan has received. The plan will be divided into two parts. Part I contains the facts, bionomic and economic, on which the proposals for future management are based and Part II these proposals. The latter are made in detail for a limited number of years (10 to 30) only; after which they will be revised in light of changes which have taken place in the interval. It is, however, generally desirable that the probable course of management over a rotation should be indicated, and the situation, which may be expected to be established as a result thereof, stated. The following is a brief statement of the ground which will probably have to be covered in each part of the plan.

PART I

1. Location, distribution, area, boundaries, and legal position of the forest.

2. Configuration of the ground with regard to its effect on silvicultural treatment, methods of management and extraction of produce.

3. Climate, geology and soil with regard to their effect on the character of the crops, and, hence, their effect on the silvicultural treatments which can be employed.

4. Results of ecological survey. Species. The character of the crop resulting from the features under the last two headings and from the history of climatic disturbances and of biotic influences, *e.g.*, interference of man, etc.

5. Injuries to which the crop is liable, whether from nature, man, animals, insects, fungi, etc. These will suggest the protective measures to be adopted and may influence the choice of silvicultural system and method of management.

6. Economic considerations. Requirements of the surrounding population, market conditions, facilities for the extraction of produce, etc.

7. Statistics of growth and yield and distribution of age classes; required for the purpose of calculating future yield.

PART II

1. *Species and Silviculture.*—The species to be grown, and, if more than one, the proportion of each. The cultivation of mixed or pure crops and the silvicultural treatments to be applied will be discussed in relation to the objects of management, the capacities of localities and the present condition of the crops.

2. *Division into Working Circles.*—If an essentially different treatment is to be applied to different parts of the area, as may be the case, for example, where both broad-leaved and coniferous forests are present, or where part of the area will be worked as high forest and part as coppice, then the compartments to which one and the same treatment is to be applied will be allotted to one working circle. If different working circles are established, then each must be dealt with separately in discussing the silviculture and regulation of the yield and in making the required prescriptions.

3. *Regulation of the Yield.*—The choice of rotation and the method of regulating the yield, to meet the objects of management and in relation to the constitution of the crops, will be discussed, and the division of the area into felling series and cutting sections laid down.

4. *Calculation of the Final Yield.* — The yield and the method of determining it will be stated and a tabular statement of the annual fellings given.

5. *Regulation of the Intermediate Yield.* — An annual or periodical programme for thinnings, and any other fellings required, will be drawn up, and the yield, which will be obtained from these, estimated in so far as is possible.

6. *Rules* for the guidance of the executive officer in silvicultural treatment will be drawn up.

7. *Cultural Operations.*—The sowing, planting, cleaning, weeding, etc., requirements will be dealt with.

8. *Miscellaneous Prescriptions* will deal with protective measures, drainage, construction of roads, buildings, etc.

9. *Financial Forecast.*—The probable expenditure and receipts under different headings will be given and the anticipated surplus or deficit calculated.

10. *Maps.* — It is very desirable that good maps should accompany the working plan, both to locate the crops and to illustrate the proposals. A map will be required to locate the compartments, and, if this is an accurate map on a large scale, it will serve the purpose of a boundary record. Maps may usefully be used to show the nature of different crops and soils and to illustrate the allotment of compartments to working-circles, periods, felling series and cutting sections.

11. *Appendices.*—The description of compartments and the statistical data used in calculating the yield will generally be attached to the plan in the form of appendices.

12. *Control and Record.*—Provision should be made for maintaining records of all operations, for the purpose of comparison with prescriptions and preserving that complete history of forest which will be required for drawing up future working plans. The last requirement also involves making provision for keeping a record of natural phenomena such as meteorological data, storm damage, insect attack, etc.

GLOSSARY

(with page references).

Advance Growth—Young trees which have sprung up in openings in the forest or under the forest cover, before any measures have been taken to bring about regeneration. 73, **86**, 102.

Afforestation—(1) In Feudal times: The placing of a given area under Forest Law. 1, 50.
(2) The establishment of a crop of trees on land not previously under forest. 8, **75-84.**

Age Class—Trees falling within definite age limits grouped together for purposes of management. 9, 194.

Age Gradation—Trees of one and the same age. 186.

Artificial Regeneration—The renewal of a forest by sowing or planting. 70, **75-84.**

Assimilation (Carbon dioxide-)—The formation of organic substances from carbon dioxide and water by green plants in the presence of light. 17, 24.

Bark Scorch—Injury done to the bark of trees by strong solar radiation. 21, **134-135.**

Basal Area—The basal area (s) of a tree is the area of the cross section of its stem at breast height. The basal area of a wood (S) is the sum of the basal areas of the trees composing it. 158.

Beating Up—The replacement of plants, which have died after planting, by new ones. 83.

Breast Height—The level above ground at which the girth or diameter of a tree is measured for certain purposes; 4ft. 3in. above ground level in Britain but more usually 4ft. 6in. above ground in the overseas Empire and in U.S.A. On sloping ground the height is taken from the foot of the tree on the up-hill side. 156, 159.

Cambium—A layer of living tissue between the wood and the bast which adds elements to both. 57.

Canopy—The screen or cover formed by the crowns of the trees in a wood. 44, 45.

Cantonment—The process of handing over to the holders of rights over a property, of the ownership of a part of the property, in exchange for the extinguishing of such rights over the remainder. 113.

Capillarity—The movement of liquids in very narrow channels under the action of surface tension. 43.

Carbon Dioxide (carbonic acid gas)—A gas formed of carbon and oxygen which is present in the atmosphere and forms the source of carbon in plant tissues. 32, 36, 39.

Chlorophyl—The green colouring matter of plants. 17.

Clay—A constituent of soils consisting of the very small particles of mineral matter. A soil containing a high proportion of such particles and having certain physical and chemical characteristics in consequence. **36, 42.**

Cleaning or Weeding—The removal or topping of inferior individuals or species in a young crop before the thicket stage, in order to favour the growth of better ones nearby. 87.

Clear Felling—The complete removal of the standing crop in one operation. 75, **97-99.**

Commutation—The purchase of forest rights by the owner of the forest from the right holders. 113.

Compartment—A unit of area in a forest permanently defined for purposes of description and record. 190.

Composition (of woods)—The various species that form the crop, their proportions and arrangement. The structure of a wood in plan, as opposed to "*constitution*," its structure in elevation. 66.

Constitution (of woods)—The structure of a wood in a vertical direction, *i.e.*, the distribution in height of the crowns of the trees. 67.

Coppice Shoot—A stem that has sprung from a stump and not from seed. 108-109.

Cord—The unit of volume measurement (128 cubic feet) for stacked wood, such wood often being referred to as *cordwood*. 156.

Correlation—The influence of the various organs of a plant on each other. 62.

Coupe—A felling area. 108, 110, **191.**

Cuticle—The outermost skin of leaves, etc., more or less impervious to water. 30, 33.

Cutting—A severed part of a shoot used for propagation. 76, **83.**

Cutting Section—A sub-division of a felling series formed with the object of regulating fellings in some special manner. 120, 190, 195.

Deflocculation—The dispersal of the colloidal part of the soil into the separate particles. 37.

Demarcation—The act of settling and defining the boundaries of a forest. 113, 196.

Dry Pruning—The pruning of dead branches. 95.

Ecology (Plant)—The study of plant life in relation to its environment. 4.

Entomology—The scientific study of insects. 118.

Epicormic Branches—Branches which develop on the stem of a tree, especially after surrounding trees have been removed. 73.

Epidermis—The layer of cells forming the outer covering of a plant, on the outside walls of which is the cuticle.

Euphotometric Foliage—Leaves which place themselves so as to obtain the maximum diffused light. 26.

Erosion—The washing away of the surface soil by the flow of water. 2, 7, 8, 50.

Even-aged Wood—Strictly speaking, a wood in which the trees are all of the same age, but practically one in which the trees are all of approximately the same *height*. 67, 192.

Exotic Species—A species introduced from another geographical region. 19, 182.

Expectation Value—The capital value obtained by discounting back to the present time all future receipts and costs and deducting the one from the other. May refer to the crop, or the land on which it grows; in the latter case it is known as the Soil Expectation Value (Se). 148-150.

Felling Cycle—The time which elapses between successive principal fellings on the same area. 195.

Felling Series—A management unit of area for the regulation and calculation of the yield. 190.

Final Felling—The last of the series of fellings in a shelter-wood system of regeneration. 73.

Final Yield—The yield in marketable wood obtained from a technically mature crop. 183, 198.

Financial Yield—The net yield represented by the rate of interest obtained on the invested capital. 148, 150.

Financial Rotation—The rotation which results in the maximum financial yield. 149-150.

Fire Line—A strip of ground which is kept free from inflammable material or which can be quickly cleared of such, to limit the spread of fire or form a point of attack against it. 114-115.

Flocculation—The aggregation together of the colloid particles of the soil into clumps or crumbs. 37.

Forest—(1) In Feudal times: An area of land over which the king claimed the exclusive rights of the chase. 1.

(2) General: A comparatively large area of land mainly covered with trees. 1.

(3) Forest Management: A collection of woods organised for the production of timber. 64.

(4) Botanical: A type of vegetation in which trees are the dominant members. 1, **43-46.**

Forest Bionomics—The parts of forestry which deal with trees and the forest as living organisms and communities of living organisms, subject to the laws of nature. 4, **15-141.**

Forest Ecology—The study of the relations of trees and communities of trees to their environment. 4.

Forest Economics—Those parts of forestry which deal with the forest as a productive asset, subject to the laws of economics. 5, **142-178.**

Forest Management—The branch of forestry which deals with the organisation of the treatment of the forest so as to carry out the policy of the proprietor. The practical application of the principles of forestry to a particular area. 5, 63-65.

Forest Mensuration—The measurement of forest products and of their rate of production in the forest. 5, **154-167.**

Forest Policy—The branch of forestry which deals with the social and economic aspects of forestry and its relation to other forms of human activity, especially to other ways of utilising the land. 3, **7-14.**

Forest Right—The legal right possessed by persons, other than the proprietor, to remove something from or do something in the forest. 9, 113.

Forest Valuation and Finance—The branch of forestry which deals with the valuation of forests, the relation of costs to values and the determination of the financial relations of different methods of treatment. 5, **144-153.**

Forest Utilisation—The branch of forestry which deals with the exploitation of forests, i.e. the nature and uses of forest products, methods of harvesting and transport, and the preparation of such products for use, in so far as it is done in the forest. 168-178.

Forest Working Plan—See **Working Plan.**

Forestry—The treatment of forests so that they may permanently and satisfactorily serve the interests of man. 2.

Forestry Commission—The forest authority of Great Britain, which is charged with the duty of promoting the interests of forestry, the development of afforestation and the production and supply of timber in the country. 12.

Form Factor—The ratio of the volume of a tree to that of a cylinder having the same basal area and length as the tree. 158.

Form Quotient—The ratio of the diameter or girth of a tree at half the height of the tree above breast height, to the diameter or girth at breast height. 159.

Frost Level—The height above ground, below which injurious frosts are experienced in a given locality. 22.

Frost Lifting—The lifting of small plants out of the ground due to alternate freezing and thawing of the soil. 132-133.

Frost Locality (Frost Spot, Frost Hollow)—An area in which frosts are more frequent and more intense than in the district generally. 22.

General Regeneration Period—The period which elapses between the initiation of regeneration in a wood and its completion. (See also **Special Regeneration Period.**) 100.

Geotropism—The influence of gravity on the direction of growth of plant organs. 60.

Green Pruning—The pruning of living branches. **95.**

Ground Vegetation—Small plants (young trees excepted) growing on the forest floor, such as ferns, mosses, grasses and herbs. 44, 46.

Ground Water—The body of water in the ground, accumulated above impermeable layers, completely filling the interstices to a level whose depth below the surface varies from place to place and, generally, from time to time. 29, 31, 43.

Growing Season—The period of the year during which vegetation in general or a particular plant is actively growing. 22.

Growing Stock (G.S.)—The volume of wood standing on a defined area of forest land; sometimes referred to as the Wood Capital. 154, **188-189.** See also **Normal Growing Stock.**

Habitat—(1) The geographical distribution of a species. 18.
(2) The kind of locality in which a plant grows. 18.

Hardwood—The wood of a broad-leaved tree. 170.

Hardwoods—Broad-leaved trees as distinct from conifers. 170.

Heartwood—The inner part of the wood of a tree, in certain species distinguished from the outer part by colour and physical properties. 171.

Heeling In—Placing plants temporarily in a shallow trench with their roots covered with soil to prevent them from losing moisture pending planting. 82.

Heliotropism—The directive influence of light on the growth and position of plant organs. 60.

High Forest—Forest in which the trees originated from seed, not from shoots thrown up from the stumps or roots of the previous crop. 97.

Humus—Organic matter in the soil, in process of decomposition. 36, **39, 51-53.**

Hygrophyte—A plant which requires a large supply of moisture for its growth. 29.

Hyphæ (singular: **Hypha**)—Cylindrical threadlike bodies constituting the mycelium of a fungus. 44, **126.**

Increment—The rate at which a tree or crop increases with age. Increment may be in volume, height, diameter, etc. 159.

Increment—Current Annual (C.A.I.).—The growth laid on during one year at a stated age; in practice generally obtained from the average growth for a few years above or below the age. Unless otherwise stated, refers to volume. 163-164.

Increment—Mean Annual (M.A.I.)—The average annual growth given by the quotient : $\frac{\text{total growth.}}{\text{age}}$ Unless otherwise stated, refers to volume. 144, 145, **163-164.**

Intermediate Yield—The yield of marketable wood obtained from a crop as the result of thinnings, etc., before it reaches technical maturity. 184, 199.

Intermittent Yield—The money or wood income obtained at irregular intervals from a forest not organised for continuous production. 185-186.

Knot—A defect in timber caused by the inclusion of the base of a branch in the wood of a tree stem. 57, 172.

Larva—The growing and feeding stage in the life of an insect which undergoes a complete life cycle, *e.g.* caterpillar, grub, maggot.

Law of Minimum—" That factor of plant nutrition present in minimum determinates the growth." 19.

Leaching—The washing away of substances by the percolation of water through the soil. 37, 40, **42.**

Light Demander—A species which requires abundant light for its growth. 25.

Light Felling—The cutting of a considerable part of a forest crop in order to admit abundant light, so as to induce the remaining trees to grow more rapidly. It involves a permanent or prolonged breach of the canopy. 94.

Light Increment—The increase in the rate of growth of individual trees which follows when they are isolated, after growing in closer stand. It is not entirely due to increased access of light. 94.

Light Leaves—Leaves which have originated and developed in a good light. They have a characteristic structure in certain trees. 27.

Limiting Factor—That factor in the environment which, owing to its unfavourable condition, has the greatest effect in limiting growth in a particular case. 20, 51.

Litter—The dead leaves, twigs, and other debris shed by the trees and other vegetation and lying on the forest floor. 39, **51.**

Loam—A soil of medium texture—not too heavy or too light. 37, 43.

Locality—The sum of all the local conditions influencing the growth of plants and plant communities (*e.g.* trees and forests), such as climate, soil, the activities of animals, etc. 19.

Locality, Factor of—The various items which go to make up the climatic and other conditions affecting the growth of plants, *e.g.* light, heat, water, etc. 19, **20-43.**

Mast—The fruit of forest trees, especially oak and beech.

Mature—A term generally used in a technical sense in reference to a tree or crop which has reached the age and size required by the management. 183.

Mean Annual Increment—See **Increment.**

Microclimate—The climate of a particular site as distinct from that of the region in which it lies. 23.

Mixed Wood—A wood consisting of two or more species in significant proportions. 66.

Mould—Well decomposed organic matter, forming a crumbly mass in which the structure of the plant parts from which it originated cannot readily be distinguished. 52.

Mycelium—The vegetative portion of a fungus. Composed of **Hyphæ** (*q.v.*). 126.

Mycorrhiza—The symbiotic union of fungi with the roots of plants. 41.

Natural Regeneration—The starting of a new forest crop by seed shed naturally on the ground or by shoots springing from parts of the previous crop, such as roots, stumps or boles, left undisturbed. 70, **71-86.**

Normal Forest—A forest containing a normal series of age gradations or classes. 186-189.

Normal Growing Stock (N.G.S.)—The growing stock in a normal forest. See also **Normal Forest** and **Normal Series.** 187-188.

Normal Increment—The increment of a **Normal Forest.**

Normal Series of Age Gradations (or **Classes**)—A complete succession of age gradations or classes from one year old to rotation age, in the correct proportions, so that an annual or periodic felling of ripe woods results in an equalisation of the annual or periodic yields. 186.

Notch Planting—Methods of planting small trees in which a notch is made in the ground and the roots inserted without further cultivation of the soil. 83.

Occlusion—The process by which wounds on trees are healed by an outgrowth of callus. 58.

Offence, Forest—A breach of Forest Law or a regulation made under such law. 113.

Pan—A hard layer in the soil at some distance below the surface, caused by the accumulation of mineral and organic substances washed down from the upper layers. 42, **52.**

Parasite—An organism which subsists on another. 125.

Peat—A soil consisting of partly decomposed plant remains. 52, 83.

Phloem—The tissues of the rind and inner bark. 57.

Physiological Dryness—Dryness of a locality, not due to absolute shortage of water, but to its being hardly available for plant life. 29.

Pitting—A method of planting in which a small pit is made for the reception of the roots, the soil being filled in after they have been placed in position. 83.

Planting Out—The planting of trees on the forest area. 80-83.

Precipitation—The water which reaches the earth in the form of rain, snow, hail, hoar-frost, etc. 28.

Preparatory Felling—A felling made to prepare the crop and soil for regeneration. 72.

Pressure Wood—Wood of abnormal structure produced in parts of stems of conifers when growing in a curve. 61.

Protoplasm—The viscous, living substance of plants, which is responsible for all the vital processes. 27.

Provenance—The ultimate source from which seeds are obtained as defined by the locality in which the mother trees grew and sometimes also by the nature of those trees. 76.

Pruning—The artificial cutting off of branches from the stems or crowns of trees. 94-96. See **Green-** and **Dry Pruning.**

Pruning Natural—The falling off of dead branches owing to decay. 88.

Pupa—An inactive stage in the development of certain insects during which internal changes take place, resulting in the emergence of the imago or perfect insect. 116, 122.

Pure Wood—A wood consisting entirely or almost entirely of a single species of tree. 66.

Pseudo-Mycorrhiza—False mycorrhiza in which the fungus is a parasite on the tree roots. 41.

Quality of the Locality—See **Locality.**

Quarter Girth Measurement—In Great Britain, one-quarter of the measured girth of a tree or log, instead of the full girth, is usually recorded, and the volume is obtained by multiplying the square of the quarter girth by the length. 155.

Raw Humus—Humus which is not in an advanced stage of decomposition. 40, 41, **52.**

Regeneration—The renewal of a forest crop. 2, **70-85.**

Regeneration Period—The period which elapses between the initiation of regeneration in a wood and its completion. (See **General and Special Regeneration Period.**) 73.

Relative Humidity—The ratio of the amount of water vapour actually present in the air to the amount which would be present if the air were saturated. It is generally expressed as a percentage coefficient. 28.

Respiration—The process by which a plant takes in oxygen from the air and gives off carbon dioxide. 18, 36.

Root Pressure—The forcing of watery sap into the wood of a stem by osmotic force in the roots. 17.

Root Swelling—The thickened basal part of a tree stem which tapers more rapidly than the main part of it. 58.

Rotation—The period elapsing between the formation of a wood and its final harvesting. 11, 99, **144-145, 184-185.**

Run Off—The flowing away of water over the surface of the soil without penetrating into it. 29, 50.

Saprophyte—A plant which nourishes itself on dead organic matter. 125.

Sapwood—The outer part of the wood of a tree which contains living cells and takes part in the physiological processes. 171.

Secondary Felling—A felling made in the shelterwood to allow more light to reach the young plants which have appeared as the result of previous fellings, but still leaving some of the shelterwood trees. 73.

Seed or **Seeding Felling**—The first felling made in a shelterwood system of regeneration, which is intended to encourage seed to germinate and young seedlings to grow. 72.

Seedling—A plant originating from seed which has grown up *in situ.* (See **Transplant.**) 78.

Seepage—The drainage of water down a slope *through* the soil, as opposed to surface run-off. 50.

Selection System—A system of silviculture in which exploitation and regeneration are carried out continuously by the annual or periodic felling of selected trees all over the area, regeneration taking place in the openings thus made. 74, **105-107.**

Shade Bearer—A species capable of surviving and growing under shade. 25.

Shade Leaves—Leaves which have originated and developed in shade. 25.

Silviculture—The cultivation of woods so as to satisfy man's requirements for their products in an economical and systematic manner. 4, **63-111.**

Slash—Rubbish, such as branchwood, twigs, etc., left on the ground after a forest crop has been cut and removed. 75, 76.

Soil Respiration—The liberation of carbon dioxide by the activity of micro-organisms in the soil. 33.

Soil Water—The water retained in the soil in and round the particles, which does not tend to drain out by gravitation. **29, 43, 50.**

Softwood—The wood of a coniferous tree. 170.

Softwoods—Conifers.

Special Regeneration Period—The period which elapses between the initiation and completion of regeneration in a given part of a wood, where regeneration of the wood as a whole is spread over a longer period. (See **General Regeneration Period.**) 74, 104.

Spore—A cell which, separated from its parent plant, is capable of development into a new individual. 127.

Stand—The crop of trees in a wood.

Stem Analysis—An investigation into the growth throughout life of the stem of a felled tree, by means of ring countings and measurements made in cross sections of the stem at fixed intervals throughout its length. 161-163.

Stomata—Pores or apertures in the epidermis leading to intercellular spaces communicating with internal tissues. (Singular, **Stoma.**) 17, 30.

Sustained Yield—The wood or money income obtained annually or at regular intervals, when a forest is managed so as to produce a a regular sequence of woods or trees ripe for felling. 186.

Symbiosis—The living together of dissimilar organisms to their mutual benefit. 40, 41.

Thinning—Cutting down some of the trees in a wood in order to affect favourably the growth and quality of the remainder. 87-94.

Thinning Cycle—The time which elapses between successive thinnings on the same area. 93, 193.

Timber—Wood above a certain diameter or girth, fixed by custom or agreement. 168-174.

Transpiration—The emission of water vapour from the stomata of plants. 17, **28, 30,** 33.

Transplant—A plant which has undergone the process of transplanting, in distinction from a " Seedling " which has not. 78.

Transplanting—The lifting of a young plant from one place and planting it in another in the nursery, in order to improve its root system and form for subsequent planting out on the forest area. 78.

Tropophytes—Plants which are hygrophilous or xerophilous according to the season. 30.

Turf Planting or **Mounding**—A method of planting, employed chiefly on peaty soils, by which turves are cut from drains and used as mounds for the plants. 83.

Underplanting—The planting of a second crop of trees under one already established. 76, **98-99.**

Underwood—A lower crop of trees or coppice shoots growing under a higher one. 66, 94, **98-99,** 109.

Uneven-aged Wood—Strictly speaking, a wood in which the trees are all of the same age, but practically one in which there is considerable range of height classes. 67.

Uniform System—A system of regeneration under a shelterwood in which conditions are made as uniform as possible over the area, with the object of bringing about regeneration in all parts of it, as far as possible, at the same time. 74, **100-101.**

Volume Table—A table giving the average volumes of trees of a certain species growing in defined localities, according to girth or diameter at breast height and total height. 158.

Wood—I. (1) General: An area of land covered with trees. 1.
(2) Technical: An area of land with a crop of trees sufficiently uniform in character to be submitted to one method of treatment. A silvicultural unit in a forest. 64, **65-70.**
II. The material which forms the bulk of the stems and branches of trees. 57, **168-174.**

Working Circle—An area under a working plan, subject to one and the same silvicultural system and set of prescriptions. 198.

Working Plan—A document which sets forth the aims of the management and the scheme of operations by which it is hoped to attain them. 6, **196-199.**

Xerophyte—A plant which can subsist with a small amount of moisture. 29.

Yield Table—A tabular statement which gives the course of development of an even-aged wood of a certain species up to a certain age, usually at intervals of 5 or 10 years. 147, **164-166.**

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